DRAINAGE OF IRRIGATED LAND

Clyde E. Houston

Poor surface drainage can result in field scalding like this.

Drainage of Irrigated Land

Drainage systems are often complicated and expensive, but when properly installed they can be made to pay off in better crops, soil conservation, improved health conditions, and greater convenience for the farm operator.

This circular helps to answer many questions arising before and during installation of a drainage system.

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Drainage of Irrigated Land

CAUSE OF DRAINAGE PROBLEMS

DRAINAGE IS THE DISPOSING of excess irrigation water or rainfall to prevent injury to crops, to prevent salt accumulation in soils, to allow earlier planting of crops, and to reclaim potentially arable low-lying overflow or swamp areas. Drainage systems are expensive to install, but they are practical where the increased value of agricultural production is greater than the cost of the drainage system. Intangible benefits such as improved health conditions and greater operating convenience to the farmer also may be important considerations.

Irrigation is Primary Cause

Drainage is necessary to successful irrigated agriculture even though losses during water conveyance and application create most of the drainage problems in irrigated areas of the West. Over one half of California's irrigation water is obtained by diversion from streams and rivers carrying natural stream flow or stored water. This water is conveyed to the point of use through many miles of irrigation canals and ditches where losses of from 20 to 30 per cent are quite common, with some losses as high as 50 per cent. The magnitude of this contribution to drainage problems can be realized when we consider that over 25,000 miles of canals and ditches, not including farm ditches, convey water to California farms. Some of these are lined but the largest percentage are unlined. The methods of applying irrigation water to soil do not permit absolute control and from 40 to 60 per cent may be lost to deep percolation and surface runoff. Sprinkler irrigation can decrease these losses but only about 15 per cent of the irrigated land in the state utilizes sprinklers.

Deep percolation beneath the plant root zone may be essential to the maintenance of a favorable salt balance in the soil. This is especially true where irrigation water is high in salts, and even where the water is low in salts difficulty may occur over a period of years unless sufficient water is percolated through the root zone or into a drainage facility to remove the soluble salts from the area. It has been suggested that increasing water costs may decrease water losses during irrigation, but with most crops grown in California irrigation costs are such a small percentage of over-all production costs that it would take a major cost increase to promote appreciable water savings by this means. At present, water costs within the state range from practically

Mosquitoes are a common occurrence in pastures poorly irrigated or drained.

Salts concentrated on surface of a field due to high water-table conditions.

nothing to $85 per acre-foot and drainage problems exist at both extremes. Therefore, it may be concluded that drainage accompanies irrigation and where surplus irrigation water is unavoidable or is a result of the method of water application, it remains a potential cause of drainage problems.

Other causes are rainfall and lateral subsurface water flow which contribute to drainage problems, but by far the major contributors are excess irrigation water and ditch and canal seepage.

Frequently the effects of excess water are not felt at the source of original use but may appear some distance away. Under favorable subsoil and topographic conditions, water applied as irrigation may move underground several miles downslope to reappear in the form of a drainage problem. Usually the flood plain areas adjacent to a stream have been irrigated first, because of the ease of diverting the water. As irrigation expanded, higher lands were developed with resultant drainage problems on the lower-lying lands.

Indications of drainage problems. Standing water or salt deposits on the surface of the ground indicate the need for drainage. In cases where these easily observed conditions cannot be seen the effects of poor drainage may be overlooked. Some of these are described in the following conditions:

Scalding of crops by summer water

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DEPTH TO WATER
WELL-THESSELL NO. 16
SOLANO IRRIGATION DISTRICT
CALIFORNIA

FEET TO WATER   **FEET TO WATER**

FIRST FULL SEASON OF IMPORTED WATER

GROUND SURFACE

YEARS
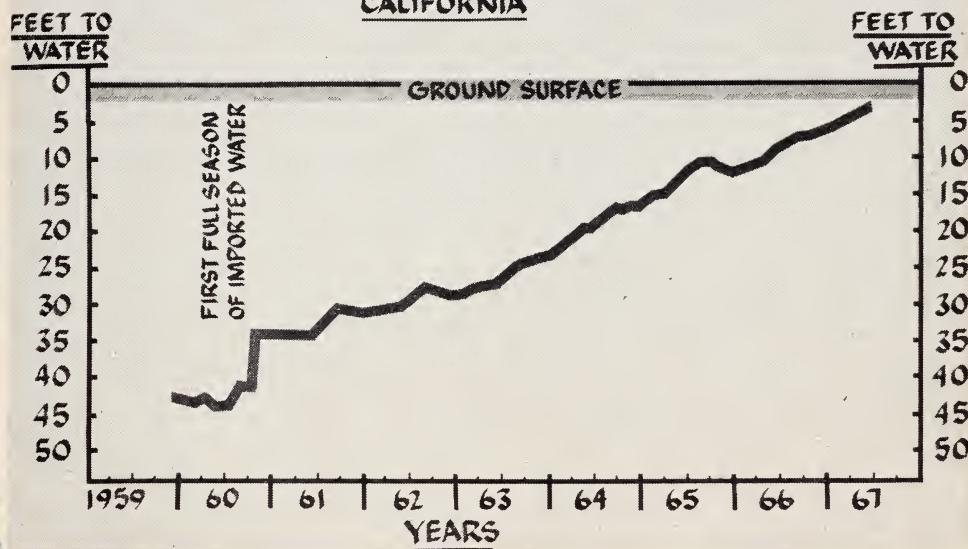
As irrigation water is imported into an area, excess water from irrigation and seepage from canals and ditches contributes to a rise in the water table under the lands irrigated. This graph of water level measurements shows how the water table rose from slightly over 40 feet to less than 5 feet from the ground surface in less than 7 years after irrigation water was imported into the area.

ponding. In the hot valleys of the state, irrigation water ponding in depressions or at the lower ends of hay and pasture fields will kill planted grasses or legumes. The solution is proper land grading with a tail water pickup ditch or return flow system.

Propagation of mosquitoes in irrigated fields. These are fields not properly graded or in natural terrain which allows water to accumulate for a sufficient length of time to produce mosquitoes. Mosquitoes create a health hazard to a farmer and his family as well as to the livestock. The city dweller also has a direct interest in drainage from this standpoint.

Soil compaction and resultant poor water penetration. These problems are sometimes directly related to moisture conditions in the soil. Under con-

ditions of poor drainage, soil compaction by traffic (tractors, et cetera) with the resultant poor water penetration is more prevalent than under conditions of good drainage.

Farm operations are difficult. This handicap exists when poorly drained soils do not furnish a firm foundation for plowing, planting, cultivating, spraying, and harvesting.

Salts accumulate in poorly drained land. Salts are removed by leaching and leaching is impossible without satisfactory drainage. Most salinity problems can be traced to poor drainage conditions.

Poor root environment. This occurs where a high water table condition decreases the natural rooting depth of a crop and cuts off the oxygen supply to the plant. This condition will gen-

[5]

Salt concentrations in this area preclude any agriculture until soil is leached and drained.

erally decrease the production of a plant, and may actually kill the plant under conditions of a fluctuating water table.

Plant diseases thrive with fungi. Under conditions of high soil moisture, most instances of fungi attack upon plant roots can be traced to poor drainage conditions.

Uneconomic plants eventually develop in poorly-drained areas. These plants are water grass, sedges, dock, cattails, tules, and other water-loving growth.

Plans developed for introducing water to land, either as a supplemental supply or for new irrigation, should provide for removal of excess water from the land.

DRAINAGE INVESTIGATION

The solution of any drainage problem is dependent upon a thorough investigation of the area affected. Many drainage problems can readily be seen in surface conditions such as injury or death to crops, visible evidence of salts, topography of the land, location and condition of canals and ditches, perpetually moist areas, and water ponded on the ground surface. In other instances effects may not be seen so readily, such as a gradual decrease in crop production because of high water table conditions, salinity in the root zone, or diseases in the plant roots caused by excess subsurface water. No matter what the cause or the results, in most cases it is a condition prevailing in that area and any investigation and solution must be based on that condition.

Determine Source of Drainage Water

The first step in solving a drainage problem is to determine the source, direction of movement, and amount of damaging water. The solution may be evident with a few simple observations, but generally it is more difficult and requires a thorough investigation. Water ponded on the surface of fields can be seen, and a simple solution is to grade the field or lead off the water in surface ditches or shallow grassed waterways. Where seepage from canals or ditches is noticeable on the ground surface an interceptor ditch next to the canal may remove the water before it gets to the field to damage crops. With more complicated problems, farmers usually do not have the technical experience to evaluate the necessary water and soils information if and when it is obtained. Also they may not be

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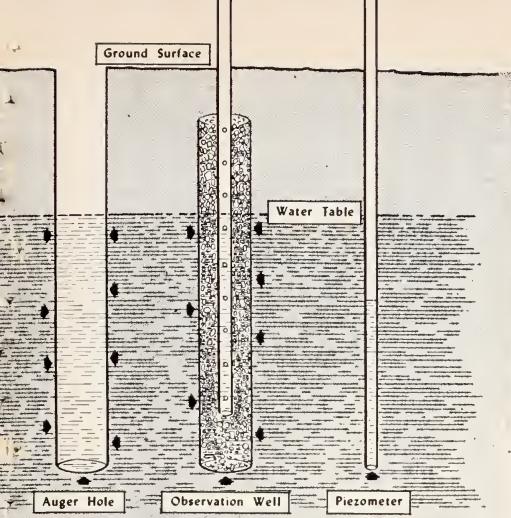
Auger hole on left, observation well and
piezometer well on right.

familiar with successful methods of design and types of drainage. Reliable engineering advice is available, and this should be used in investigating, planning, and constructing drains in order to be assured that all factors are considered for maximum benefits at minimum cost. The investigation itself is usually carried out in two parts.

Collecting Information

First, all available information is collected and analyzed. Rainfall and runoff records should be studied to learn the intensity and total amount of water which may be contributing to the drainage problem. Topographic and aerial maps will show ground slopes, channel locations, sites for suitable outlets for drains, and areas subject to water ponding. Soil surveys will show general soil characteristics to depths that are relatively shallow— less than 5 feet. Well logs may indicate presence of artesian water and subsoil stratifications confining or perching water. Water delivery records may indicate water shortages produced by ditch seepage or water use in excess of need. Seldom is sufficient information developed in the first step of an investigation for a satisfactory determination of the source and solution to the drainage problem.

Field Investigations

Field investigations are made to collect missing data necessary for the proper system design. The field investigation may start with an inspection of any plants that appear to be affected. Soil should be removed from around the roots to expose conditions of both soil and root.

Soil auger. Probably the most valuable tool for investigating a drainage
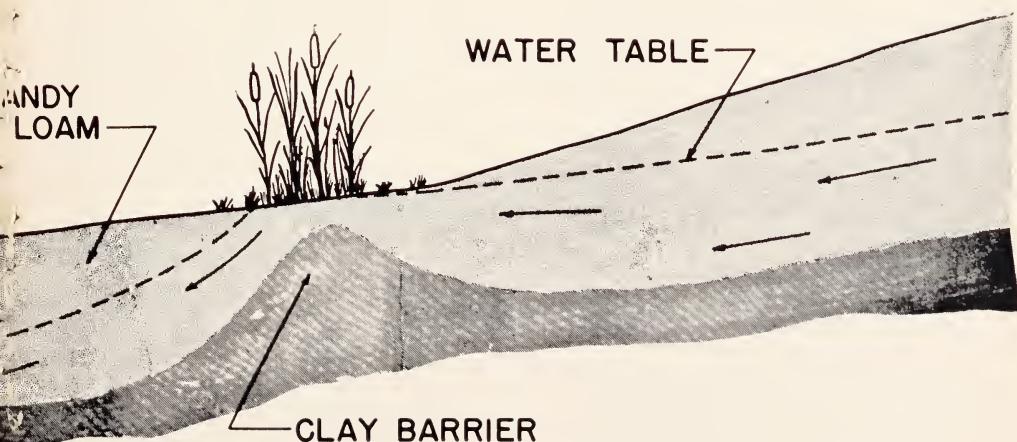
Common condition causing bogs or wet spots in fields. Auger holes are the only means of
locating the problem causing clay barrier.

[7]
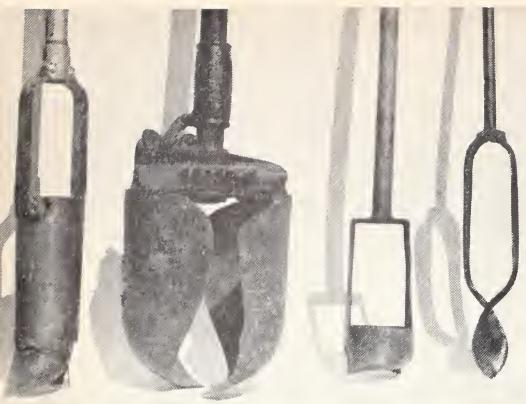
Soil augers used for drainage investigations. Left to right: screw type; orchard type; post hole; modified orchard; Dutch auger. When properly built the Dutch auger has been found most satisfactory in wet soils usually encountered in drainage investigations.

the hole and gravel backfilled into the hole around the pipe. The pipe should extend aboveground a foot or two. The bottom 3 or 4 feet of the pipe should be perforated with several dozen small holes in order to assure that water coming from all strata will contribute to the static water level beneath the ground. The pipe may be steel, downspout material, plastic, or any material sufficiently strong to keep the hole sides from filling in.

The wells should be installed in and around the problem area as near to a grid system as possible. They should not be placed in cultivated fields unless they are near a tree or other permanent structure, as cultural tools may strike them and damage the pipe or equipment. A good basic plan is to

problem is a soil auger. This instrument, about 2 to 4 inches in diameter, is used to explore subsurface soil conditions and to construct observation wells. In the process of augering holes, information is obtained on the location and characteristics of subsurface soil strata; the relative permeability of augered material may be indicated; the location and level of damaging water can be determined; and the presence or absence of a confining soil strata may be discovered. Depth of auger holes depends upon the problems encountered, but when possible 10 feet should be the minimum for most investigations. The more holes augered the more detailed the investigation and more accurate will be the drainage-system design. In most water table investigations a determination of the source and extent of the water cannot be developed immediately but necessitates an observation program through an irrigation cycle or season. When this is required, several inches of gravel should be placed in the bottom of the hole; a pipe, numbered with paint in order to be located easily for measuring, should be inserted in

Dimensions for the Dutch auger.

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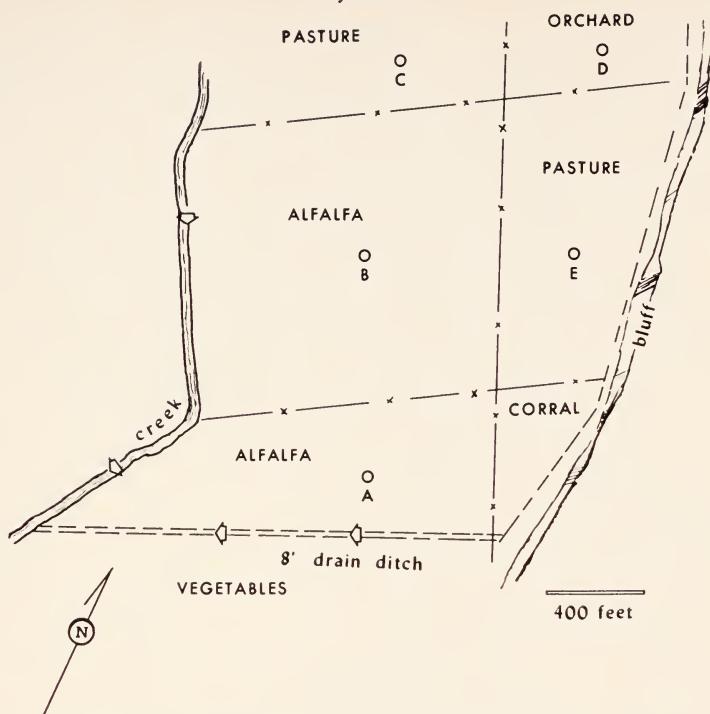
1. Preliminary investigation consisting of inspection of crops, topography and auger holes A, B, C, D, and E indicate a more detailed investigation needed. Auger holes indicated a loam soil underlain with a clay pan at about six feet. Area being damaged by poor drainage is the alfalfa field containing auger hole B.

place them along the fences and edges of fields or near standpipes where available. Locations near ditches should be avoided because water in the ditches may give erroneous readings. Depths of water in the wells should be measured and recorded before and after irrigation during the growing season, and monthly or after storms during the nongrowing season. A topographic survey should be made of the field including elevations of the observation wells. From this information can be determined ground water elevations, ground water contours, and flow direction of ground water. Any changes in water levels and flow patterns can be correlated with precipitation, with water levels in adjacent streams or canals, and with irrigation in the problem area or adjacent fields.

Piezometer. Where artesian water is suspected, a different type of well is used in the investigation. This instrument, called a piezometer, is a small $\frac{1}{4}$- to 1-inch diameter nonperforated pipe driven or jetted into the soil with the end located in the stratum containing the pressure water. To drive a piezometer, insert a rivet in the end of the pipe to keep soil from entering, then drive the piezometer by hand with a fence-post type of hammer. After it is driven to the desired depth a rod is inserted in the pipe and the rivet is pushed out into the soil. The rod is then removed and a cavity at the bottom of the piezometer is created by jetting water from a plastic tube inserted down the piezometer. Water can then enter the pipe and rise to the height representing the pressure in the

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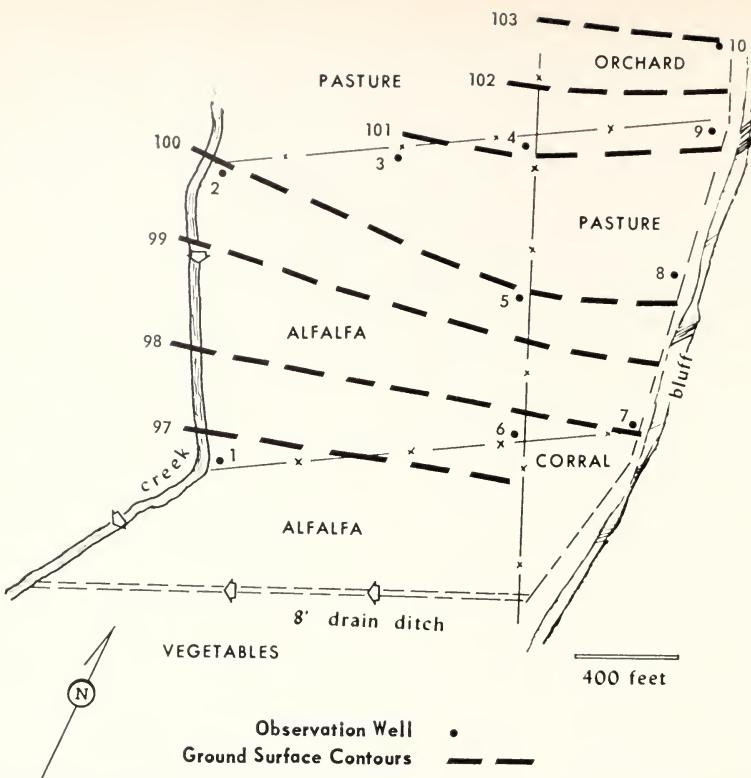
2. Observation wells installed at points 1 through 10. Levels run to determine ground slope and elevation of bench marks at observation wells.

soil at the end of the pipe. For depths greater than 15 or 20 feet a jetting outfit can be used. This consists of pipe through which water is pumped under high pressure. The water pressure re-

moves the soil and the pipe is pushed into the hole created. As greater depths are desired, additional sections of pipe may be coupled to the pipe already installed in the ground and jetting is continued. Care must be exercised to fill the annular space around a jetted piezometer.

Piezometers may be installed in groups with the ends terminating in different strata or at different depths in order to measure pressure differentials of the water-bearing strata.

When equipment is available, continuous records will give a much better record of water table fluctuations. There can be unrecorded variations in the water level when measurements are made manually at intervals of days or weeks.

A power auger is necessary for area-wide drainage investigations.

ORCHARD
101 • 10
PASTURE
98 99 100
97 x
96 •2 4• 9•
3•
ALFALFA
8•
95 5• PASTURE
94
bluff
93 6• 7•
creek •1 x
CORRAL
ALFALFA

8' drain ditch
VEGETABLES
400 feet

N

Observation Well •
Ground Water Contours ▬▬ ▬
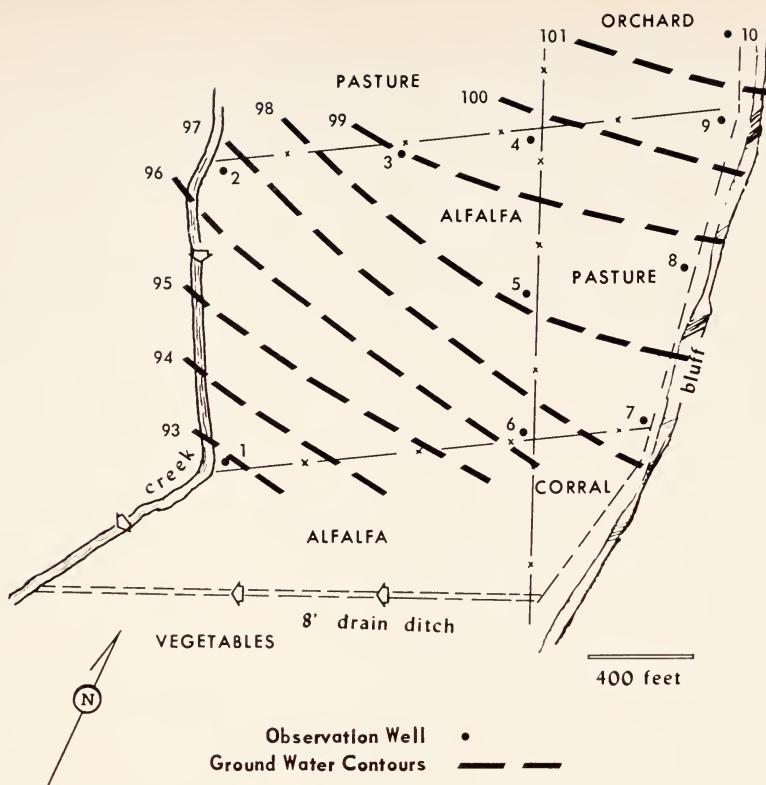
3. Water levels measured monthly for one year and ground water contours drawn for month of highest water table. Contours indicate water is moving from northeast to southwest.

Estimating soil permeability. An important factor needed in the design of a drainage system is the permeability or hydraulic conductivity of the soil—which means the rate of movement of water through soil. This may be estimated by a trained technician by observation and feel of the soil at the time holes are being augered. Several direct methods have been developed for making this determination but a trained technician is required to perform the work and interpret the data.

Direct field methods make use of the auger hole or the piezometer. In the auger hole method a hole is drilled to

Equipment for jetting piezometers. Left to right, operator handling piezometer pipe to which is connected a pressure hose; pump and engine creating several hundred pounds water pressure; water tank on truck.

[11]
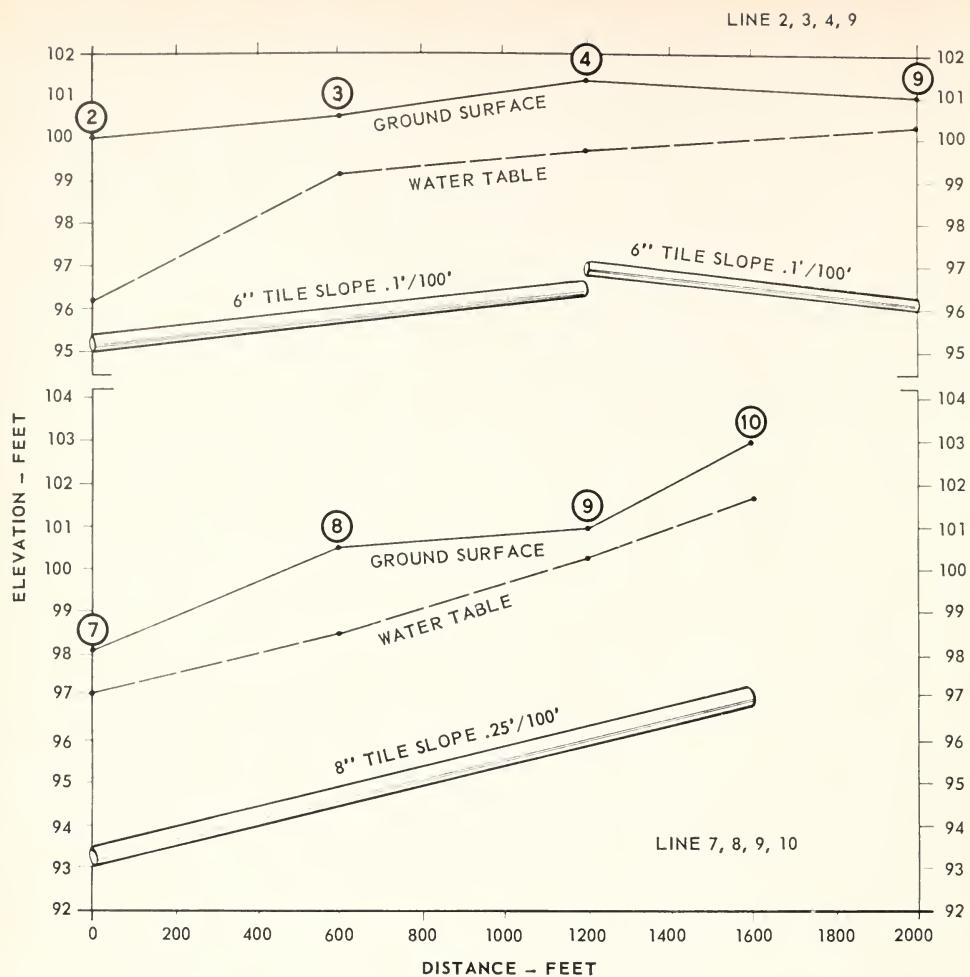
4. Profile of the ground surface and maximum water table height along a line of observation wells 2, 3, 4 and 9 indicates that two tile lines from well 4 on a slope of 0.1 per cent should intercept some of the water.

5. Profile of the ground surface and maximum water table height along the line of observation wells 7, 8, 9 and 10 indicates that a tile line on a slope of 0.25 per cent should intercept some of the water.

a predetermined depth below the water table and the water in the hole lowered by pumping with a small portable pump. After pumping stops, the rate of rise in the hole is timed and the value of hydraulic conductivity calculated from the dimensions of the hole, the depth of the bottom of the hole below the static water table, the rate of rise of water, and a formula based on a theory of water flow in soils. With the piezometer method, an open pipe is forced into the soil to the desired depth and the soil in the pipe is augered out and the unlined hole extended several inches below the bottom of the pipe. Again the rate of rise is determined after pumping and the hydraulic conductivity calculated from the several factors mentioned above. The figures of hydraulic conductivity can then be used in a formula to determine spacing and depth of drains. The drawbacks to this type of investi-
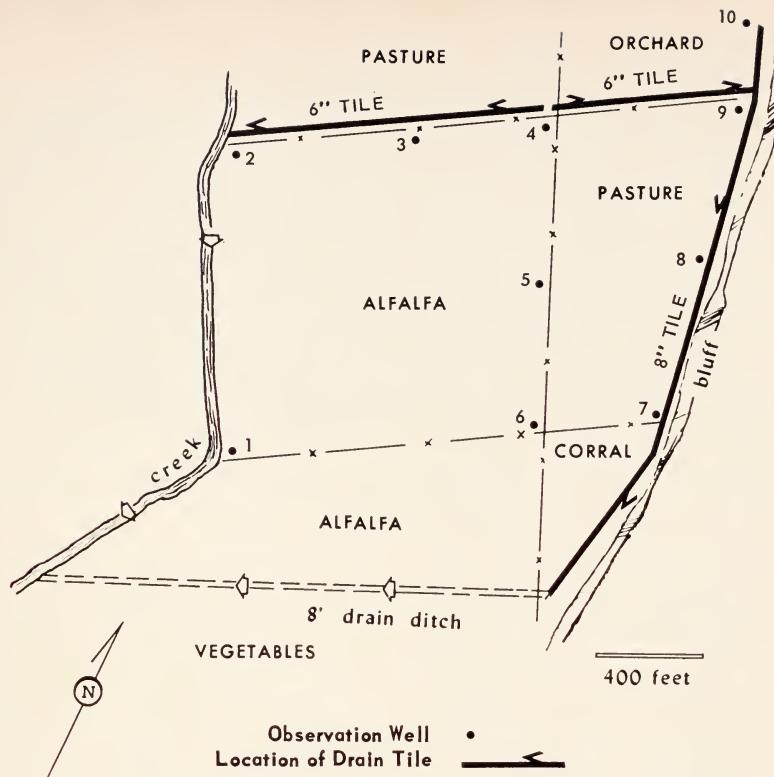
6. The tile from well 4 to well 9 discharges into line along observation wells 7, 8, 9 and 10 which in turn discharges into the open drain ditch on the south boundary. The tile from well 4 through well 2 discharges into the creek on the west boundary. Tile are placed at five-foot depths in order to conform with safety orders and to keep the tile out of the less permeable clay pan.

gation are complicated equipment and difficulty of use, combined with changes in soil texture in a problem area.

Although excellent progress has been made in recent years in developing drainage criteria and investigational tools, it still takes good judgment, local experience, and trial and error—along with a thorough understanding of basic principles—to design a successful drainage system.

DRAINAGE METHODS

Once the cause and extent of the drainage problem have been determined, we are in a position to develop a solution and design a drainage system. The two general methods for re-

moving damaging water are by interceptor drains or relief drains. The appropriate method to use depends primarily upon the flow characteristics of the excess water and the physiographic features of the area along with the subsoil conditions.

Interceptor Drains

Solves two problems. The interceptor drain may be used to remove overland surface water, or subsurface water, such as canal seepage entering an area by lateral flow above a relatively impermeable soil layer, before it reaches the point of damage. In either case the water may be effectively intercepted near the area boundary. *A good rule to follow with any drainage prob-*

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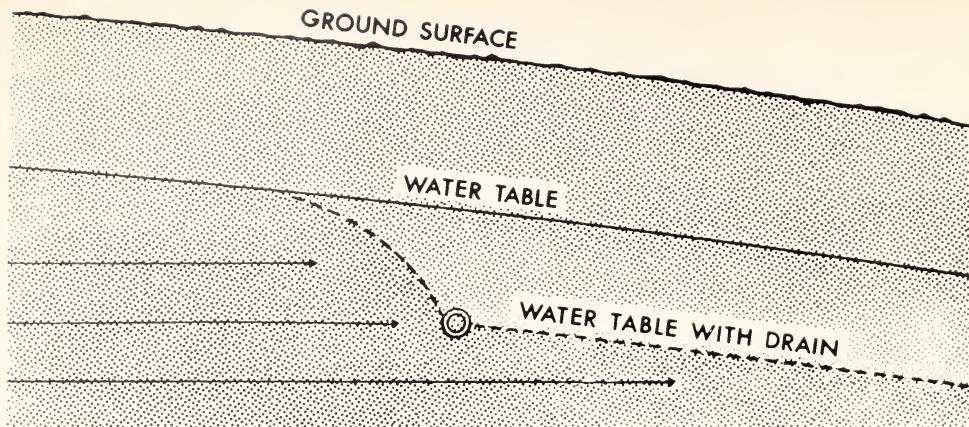
Diagram illustrates lowering of water table as subsurface water moves downslope and is intercepted by tile drain.

lem is to try to intercept the damaging water before it reaches the point where damage occurs.

Installing the drain. Installation should be as deep as possible in order that the maximum amount of water flowing over the impervious stratum may be removed. On sloping ground with subsurface water moving above a relatively impervious stratum, a drain with the bottom on top of the impervious layer will pick up nearly all of the water moving downslope. If a tile line is installed in the impervious stratum there is a possibility that much of the water moving downslope may bridge over the tile line and continue to the area of damage. With an open ditch the bottom may be excavated into the impervious stratum and part of the stratum used as a conveyance channel. On sloping ground a drain has little effect upslope relative to that downslope. The effect upslope is usually of little importance with an open drain, as such a drain is generally placed on the property boundary in order to lessen the nuisance created by an open ditch. A tile drain may be placed in the field and operated as efficiently, providing the slope is not too great. Water table conditions downslope, where the

problem area usually exists, are dependent upon changes in the ground slope, the slope of the impervious stratum, and soil texture. If there is no change in these, the water table will continue downslope at a distance above the stratum slightly greater than the water in the drain.

Relief Drains

This type of drain is used where conditions do not favor interception of water prior to its arrival at the problem area. The term "relief" is used in describing systems in which drains are installed in either a systematic or random pattern within an affected area at a predetermined spacing. The lateral lines are usually constructed in a grid or herringbone pattern, with each lateral connected to a larger mainline which in turn discharges into a trunk drain serving several farm systems.

District-farmer maintained. The Imperial Valley is a good example of this type of drainage on a large scale. About 250,000 acres are drained by over 12,000 miles of tile lines installed at a present rate of about 700 miles per year. The main tile lines discharge into large open ditches which are provided by the District to serve each 160

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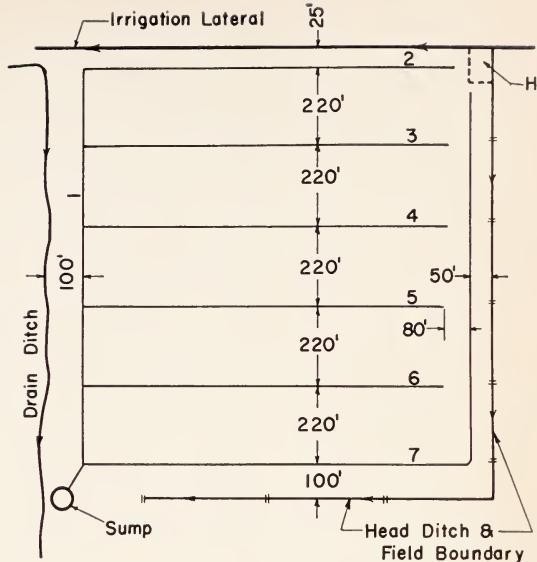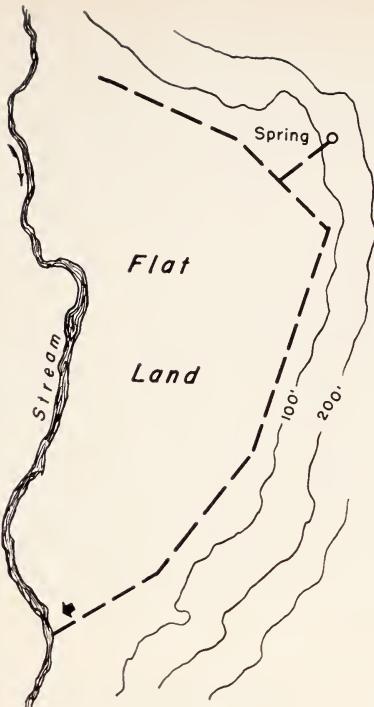
Typical interceptor and relief drain systems.

acres of land. The trunk drains then discharge into the Alamo and New rivers which flow into the Salton Sea. The practice in Imperial Valley is similar to that followed by some other irrigation districts in that the Imperial Irrigation District furnishes and maintains the outlet and the farmer is responsible for interior drainage of his land. As the primary function of the drainage system is to remove shallow ground water, the drains should be installed in the most pervious soil stratum. Spacings of 75 to 300 feet are found in Imperial Valley.

In the Oxnard Plain area of Ventura County, over 25 square miles of highly productive fruit and vegetable land are drained by many individual tile systems which discharge into large-diameter covered concrete pipe used for trunk drains. A sand stratum at 8 to 10 feet sometimes provides an excellent location for individual tile systems to remove water rapidly.

Relief Wells

Artesian water problem. Artesian water in many isolated areas poses a difficult problem which may be solved by either interceptor or relief drains and in some instances a combination of both. Artesian water may originate in higher areas where irrigation water and precipitation percolate into a conductive stratum of soil and move laterally downslope beneath the ground surface. As the water moves it may become confined between two relatively impermeable strata which do not allow movement above or below the conductive layer. As the water approaches the valley it is under pressure and may rise to the surface through natural fractures in the confining layer and cause drainage problems. This condition exists along some of California's main streams which are leveed to contain the stream within the banks. Water is usually higher in elevation on the streamside of the levee than on the
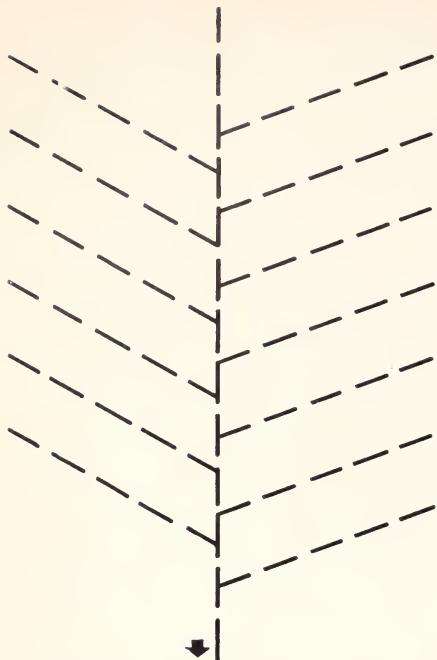
HERRING-BONE SYSTEM **GRIDIRON SYSTEM**
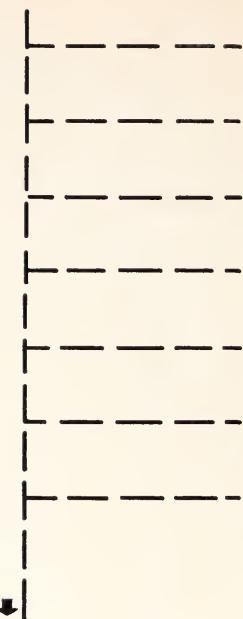
Two systems of relief drains.

field side. This differential in elevation creates a gradient for the confined water, and in many cases it finds a conductive layer of soil from the stream to some place in the field.

Wells, either pumped or free flowing, can sometimes be installed to relieve the pressure within an affected area, with the water conveyed from the area or used for irrigation. Investigations should be undertaken to determine the effectiveness of such relief wells, for where the area of influence is small the cost may be prohibitive. The relief drain may be used where artesian pressures are not too great.

OUTLETS FOR DRAINS

Requirements. No matter what type of drainage or drainage system is to be installed it is only as good as its outlet. A satisfactory outlet requires the proper capacity to carry the maximum amount of water to be removed and the proper depth to allow water to

flow from the drained area. A natural channel such as a creek or river will become the ultimate outlet in most large community or area-wide programs. For individual farms where the quantity of water for disposal is relatively small, the outlet may be a community drain, or occasionally a low-lying area which may be sacrificed for that purpose. In some areas the outlet may be an irrigation canal or lateral. These can be used if the drainage water is of such quality that it does not adversely affect the irrigation supply.

Ideal outlet. An outlet should provide a free flow of water from the drain at all times and allow for the construction of drains at such depth and capacity as to give satisfactory drainage where it is needed. Although all of the requirements of the ideal outlet may not always be met, adjustments can be made so that otherwise feasible projects may be constructed where pos-

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Tile outlet. Note the solid section of pipe extending over the water in the drainage ditch.

sible. Tile drains should discharge into open drains at least 6 inches higher than water in the open drain when it is flowing at capacity. A tile line should never "outlet" directly from the tile to the ditch. A drop structure to insure against erosion may be constructed at the ditch bank or more conveniently, a 10- to 20-foot solid section of pipe should connect to the last tile on the line and extend several feet into the ditch to avoid erosion. Tile-line outlets into natural channels may be submerged for short periods during storms.

Need for sump. In many instances water in trunk drains or natural channels is higher than the water in a drain ditch or tile line. In these instances an accepted procedure is to install a sump with a pumping plant to raise the water for discharge into the higher trunk drain. The sumps are constructed by excavating a 12- to 15-foot hole at the lowest point in the field. Into this hole is set a precast concrete

slab upon which are placed on end several sections of 6- or 8-foot diameter concrete pipe. The sump usually extends no more than a foot or two above the surface of the ground and should have a cover with an entrance hole. A small horsepower pump and motor with a float and automatic switch are installed to raise the water the needed height to allow it to flow through a pipe into the trunk drain. When water in the sump rises to the bottom of the inflowing tile lines, a rod connected to the float turns on the switch. When

Sump pump outlet.

3-5 H.P. MOTOR & PUMP

INLET TILE

ELECTRIC CONTACT SWITCHES

16'

DRAINAGE SUMP

6' - 8'

12'
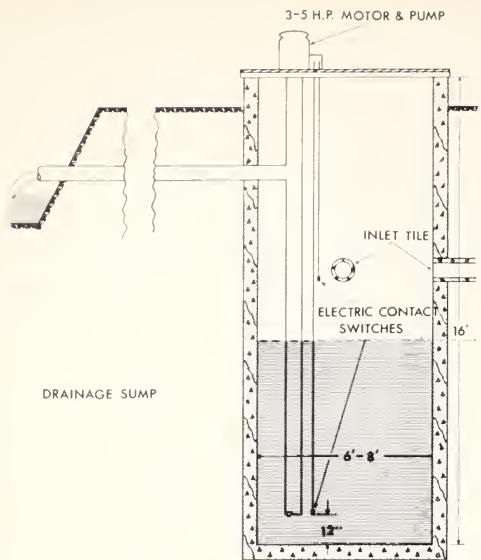
Diagram of drainage sump.

the pump has lowered the water in the sump to the lowest point without breaking suction the rod connected to the float turns off the pump; water again rises in the sump and the cycle repeats. In this way the sump is almost wholly automatic and needs very little attention. The cost of sumps depends upon location and the availibility of equipment and materials, but usually it amounts to from $1,000 to $1,500.

TYPES OF DRAINS

The preceding sections discussed the correction of drainage problems without giving particular attention to the type of drainage facilities to be used. This is proper since in general the type of drainage facility constructed depends on factors other than the nature of the problem. The purpose of most drains is to provide a flow path of low resistance for the soil water. Open ditches, tile lines, moles, French drains, and wells all serve essentially the same purpose in all parts of the world. However, certain features of construction and use of these drains may be unique to irrigated regions and to conditions found in individual areas. Factors to

be considered in selecting the type of drain are cost of installation and maintenance, value of land, and the personal desires of the individual for whom the drainage is being done.

Open Drains

Advantages. The open drain is excellent for rapid removal of large quantities of water. Water moving along the ground surface enters an open drain more rapidly than a covered drain because it does not have to penetrate the soil first to get into the drain. The initial cost of an open drain is usually less than for a covered drain. The open drain is well suited to intercepting runoff from hillsides or higher-lying areas which may be flooded by heavy rains or by overirrigation. It also serves as an outlet for tile lines when the cost of large concrete pipe is excessive. The greatest advantages of an open drain are the low initial cost and the large quantities of water which can be conveyed through it.

The size of ditch necessary to carry a given quantity of water is dependent upon the slope or grade and, to some extent, upon the shape of its cross section. The shape is determined by the texture of the soil through which the ditch is constructed. A drain intended only to remove water from the ground surface or intercept surface runoff may be designed to run full at times of maximum runoff. On the other hand, a drain intended to lower the water table must be so designed that the water surface in the drain is always below the depth at which it is desired to maintain the water table. Although open ditches may be any size, only relatively small ditches such as the individual farmer is likely to need, will be discussed here.

Side slopes. The angle or side slope of a ditch depends largely on the type of soil through which it is constructed.

In fine-grained soils, such as clay, side slopes will stand almost vertical, ½ to 1 slopes (½ foot horizontal to 1 foot vertical) are common. In coarser-textured soils 1 to 1 or even 2 to 1 may be advisable. Very sandy soils may require side slopes of 3 to 1. In quicksand it is almost impossible to maintain side slopes on drainage ditches.

In the design of an open drain some of the factors to be considered are known, others must be assumed. For example, rainfall, runoff, and excess irrigation water must be determined, but since they cannot be determined with extreme accuracy, the amount of water which a drain is designed to carry will be only an approximation. If the estimate is too small there will be times when the drain will not carry the runoff as quickly as desired. If conditions are such that the drainage must be rapid, any error in design must be on the side of safety. The slope, grade or fall of the drain can be accurately determined by measurements on the ground.

Size. With grade and side slopes decided upon, the problem is to determine the size (depth and bottom width) necessary to carry the estimated quantity of water. Elliott's formula for open drains has been found satisfactory for determining size, and because

Left: A machine-dug open drain. Because of the size needed for the desired depth, high-value land may be lost from production. Below: Diagram showing the relationship of the dimensions of an open ditch drain.
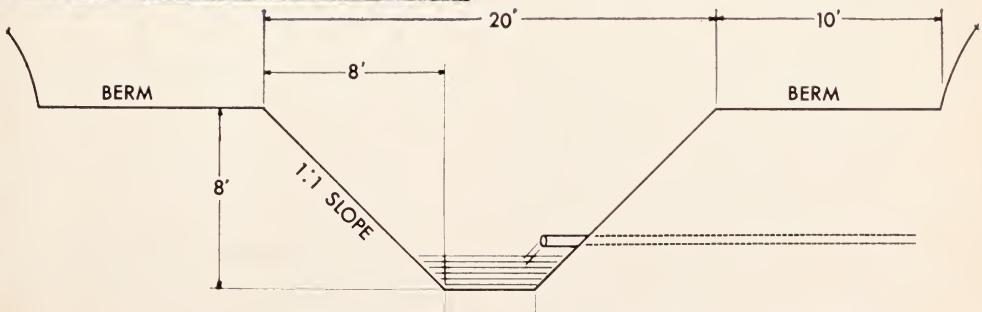
of its simplicity is more convenient than some other formulas which may, under certain conditions, be slightly more accurate.

Elliott's formula is

$$v = \frac{\sqrt{a \times 1\frac{1}{2}\, f}}{p} \qquad (1)$$

Where v = velocity of the water in feet per second.

a = area of cross section of the drain in square feet. (½ of the sum of the bottom width plus top width multiplied by the depth.)

p = wetted perimeter in feet (the bottom width plus the lengths of the side slopes which will be wetted).

f = fall or grade in feet per mile.

Q = quantity of water (discharge) in cubic feet per second. When "v" which was found by Elliott's formula is multiplied by "a" it will give the quantity of water "Q" that the drain will carry or av = Q (2). The following relations between bottom width and depth for different side slopes give trapezoidal cross sections of maximum efficiency:

ss	0	¼:1	½:1	1:1	1½:1
b	2d	1.56d	1.24d	0.83d	0.61d
ss	2:1	3:1	4:1		
b	0.47d	0.32d	0.25d		

ss = side slopes; b = bottom width; d = depth.

The following procedure may be used to determine the size of a ditch. First estimate the quantity of water to be removed. This is seldom known accurately because one cannot accurately know the amount of rain that will fall or the proportion that will reach the drain in any given time, but rainfall and other records will assist in approximating the quantity. The surplus irrigation water to be removed can be determined accurately only after a drain has been installed and the results of several irrigation cycles have been measured. Under most conditions of good irrigation

practice, from 25 to 40 per cent of the water applied must be removed by natural or artificial drainage and usually a combination of both.

Some quantity must be assumed, so let us say that we desire a drain that will carry 5 cubic feet per second (approximately 1 inch in depth from 120 acres in 24 hours). The slope of the drain is known or can be measured. Let us assume it is 5 feet per mile or about 1 foot per 1,000 feet. Let us also make the assumption that soil conditions are such that we can expect the sides of the ditch to stand on ½ to 1 side slopes.

As a trial, assume that a drain flowing 2 feet deep and 2½ feet wide on the bottom will be required. (The ideal cross section would be 2 feet deep and 1.24d or 2.48 feet wide.)

$$a = \frac{2.5 + 4.5}{2} \times 2 = 7$$

Substitute these values in formula (1).

$$v = \frac{\sqrt{a \times 1\frac{1}{2}\, f}}{p} = \frac{\sqrt{7 \times 7.5}}{6.98} = 2.74$$

The velocity of flow would be 2.74 feet per second, and substituting this value in formula (2) av = Q we have 7 × 2.74 = 19.2 cubic feet per second. It is easily seen that such a ditch will carry four times the required amount and is therefore too large. (In another trial assume a drain flows 1 foot deep and 1.24d or 1.24 feet wide.)

$$a = \frac{2 + 3}{2} \times 1 = 2.5$$

Substituting these values in formula (1):

$$v = \frac{\sqrt{2.5 \times 7.5}}{4.2}$$

= 2.1 feet per second. Substituting in formula (2) av = Q we get 2.5 × 2.1 or 5.25 cubic feet per second.

This figure is only 1/4 cubic foot per second greater than the desired discharge, and the difference is on the side of safety. Therefore, it can be concluded that a drain 2 feet wide on the bottom, flowing 1 foot deep with 1/2 to 1 side slopes, and a fall of 5 feet per mile, will be a satisfactory size for a discharge of 5 cubic feet per second.

Construction. An open drain may be constructed by hand, or with machinery such as tractor and scraper, bulldozer, tractor loader, trencher, machine shovel, backhoe, dragline, clamshell, or grader. Ordinarily, the farmer is interested only in those drains that can be constructed with equipment which he has or can readily secure.

Hand-dug drains are limited in size to drains which can be dug more cheaply by hand than by power equipment or to drains dug in places inaccessible to power equipment.

Unit production and cost figures of power equipment vary with the material excavated, size of equipment, and size of job. During eight hours of average operation, including breakdown time, a trenching machine may excavate from between 500 and 600 feet for a 5-foot trench, to between 1,100 and 1,200 feet for 3-foot trench both in a clay soil. With a 3-foot trench the eight-hour average production rate may vary from 500 to 600 feet in a clay soil to about 2,500 feet in a peat soil. There is the additional factor of size of equipment which may change these figures. The best data on rate of excavation can be obtained from the contractor when he has observed the type of soil and has been told the depth of trench desired. Shovels and backhoes on an eight-hour average production schedule can be expected to excavate with a 3/8-yard bucket from about 70 cubic yards in a sticky clay to slightly over 200 cubic yards in a moist loamy soil. With a 1-yard bucket, production for the same period will range from about 200 cubic yards in a clay to 550 cubic yards in a loam. With no breakdowns these figures could be about 30 per cent greater. With draglines the production figures will be about 20 per cent less than with shovels or backhoes.

To convert yardage figures to length of ditch determine the cubic yards in the cross-sectional area of the ditch per foot length and divide this figure into the rate of excavation. As an example, assume a ditch has a bottom width of 2 feet, side slopes 1 to 1 and is 2 feet deep. The cross-sectional area is 8 square feet and the volume for each foot of length is 8 cubic feet. Since there are 27 cubic feet in a cubic yard the yardage per running foot of ditch is 8 divided by 27 or 0.3 cubic yard. If a machine can excavate at a rate of 150 cubic yards per day then the length of assumed ditch that can be dug in a day is 150 divided by 0.3, or 450 feet. Bulldozers, scrapers, and roadgraders are limited to length of haul and depth of ditch, and efficiency is dependent to a great extent upon the operator's skill.

The material excavated from an open ditch should be either spread out over adjacent areas or placed far enough from the edge so that it will not slip back into the ditch. This "berm" should be about one half of the top width of the ditch.

In the drainage of irrigated lands, where the depth to the water table rather than the removal of surface water is of major importance, open drains are seldom used for the drainage of individual fields. Where open drains are constructed from 6 to 10 feet deep, water may flow only a foot deep. Such a drain will occupy five or more acres of land for each mile of length. Such a large ditch to carry so small a quantity of water should be avoided wherever possible.

Maintenance. An open drain can be

LAND VALUE (DOLLARS PER ACRE)

WIDTH OF DITCH, BERM AND SPOIL BANKS (FEET)

VALUE OF LAND PER FOOT OF DITCH (DOLLARS)
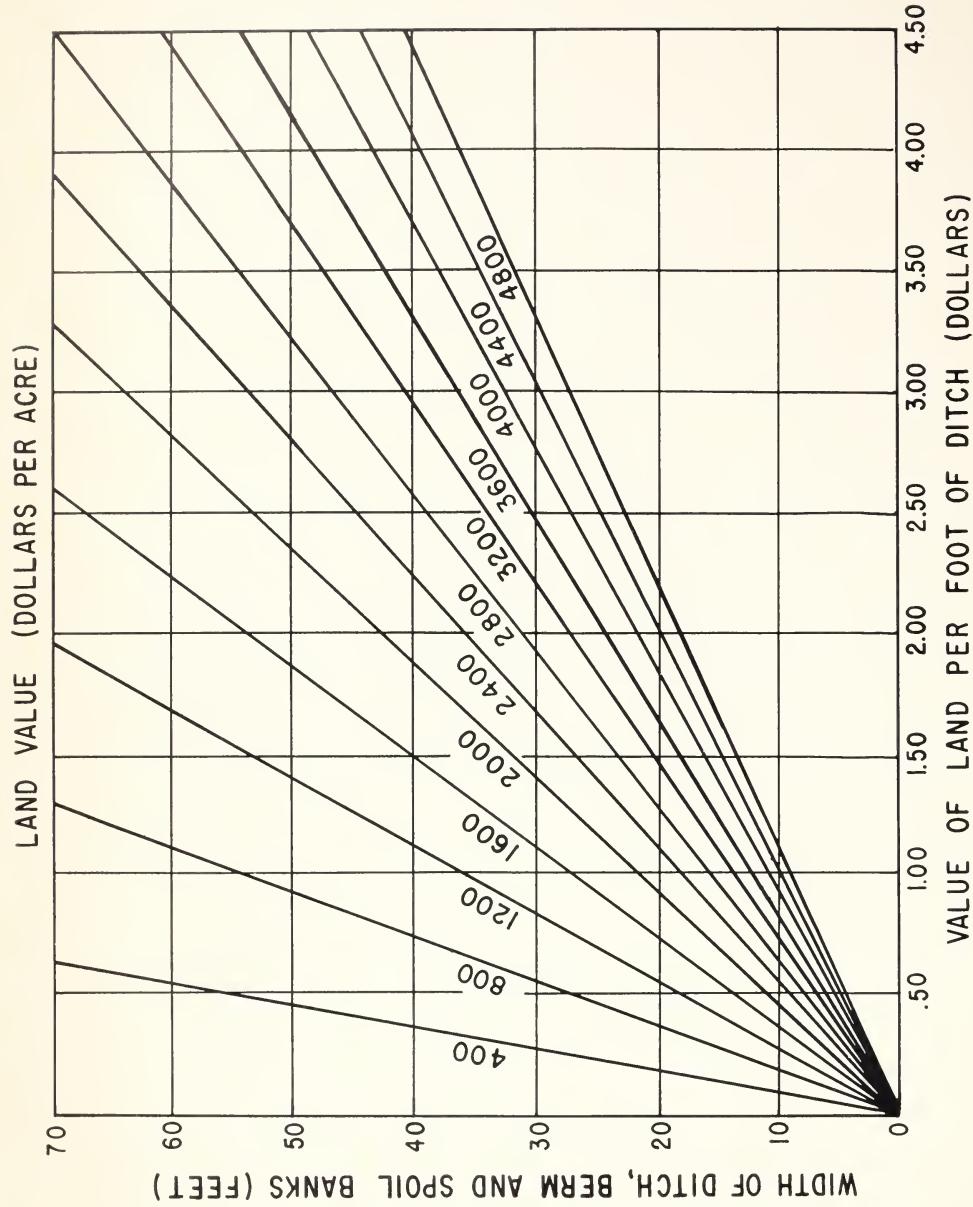
Chart showing relationship of size of ditch to value of land lost in production. Assume a drain ditch 8 feet deep uses 50 feet for ditch, berm and spoil banks of $2000 per acre land. Rising vertically on left hand scale to 50 and horizontally to 2000 then down vertically to about $2.30 as value of land per foot of ditch. Such a ditch along one side of a 160 acre square field would remove land valued at $2.30 x 2640 or over $6000.
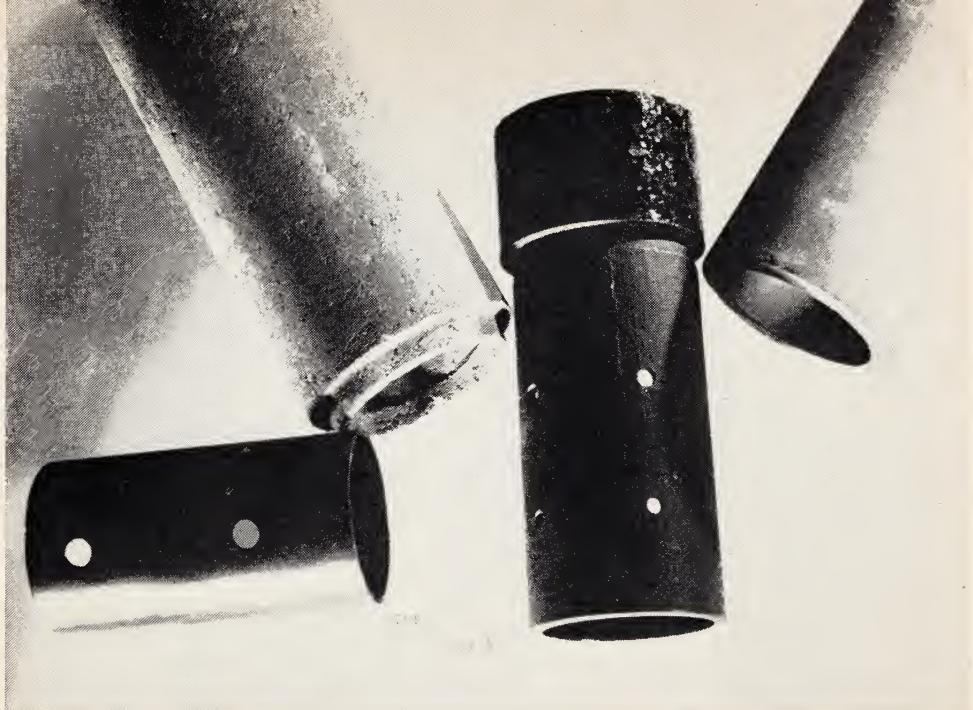
Concrete and clay tile comes in many sizes and forms. The tongue and groove joints of concrete on the upper left and square-cut end clay pipe on the right are the most popular types. Perforated plastic, on the left, and perforated bituminized fiber, in the center, are being used to a limited extent.

kept in efficient working condition only by careful maintenance. A drain allowed to become obstructed by brush, weeds, and rubbish, or whose banks have sloughed in and partially filled it can no longer provide efficient service. A drain should be cleaned out to its orginal depth when efficiency is curtailed, which is about every year or two. The amount of work and cost necessary to maintain a drain in proper condition will depend on how badly it is obstructed. Cattails, tules, and similar water-loving plants are particulary bad and may, in a few months, seriously impair the effectiveness of open drains. Cost of maintenance may, in a few years, equal or exceed the original cost of construction. Machines have been developed for ditch cleaning but, in general, machine-cleaning is done by the same type of equipment used in construction of the ditch. Burning and chemical con-trol are becoming more popular and in many instances more economical than hand- or machine-cleaning. Chemical control must be used with caution in order not to create a hazard to crops or livestock. A good rule to remember is that an open drain is only as good as its maintenance.

Tile Drains

The tile drain is built of short sections of pipe unsealed at the joints and butted together to form a continuous buried pipe line. It requires little maintenance and farming operations can be carried on over it without loss of land.

Types of tile used. Concrete and clay are the commonest types of tile used for drainage in California although perforated pipe made from bitumized fibre and plastics is being used. Reliable tile manufacturers are famil-

[23]
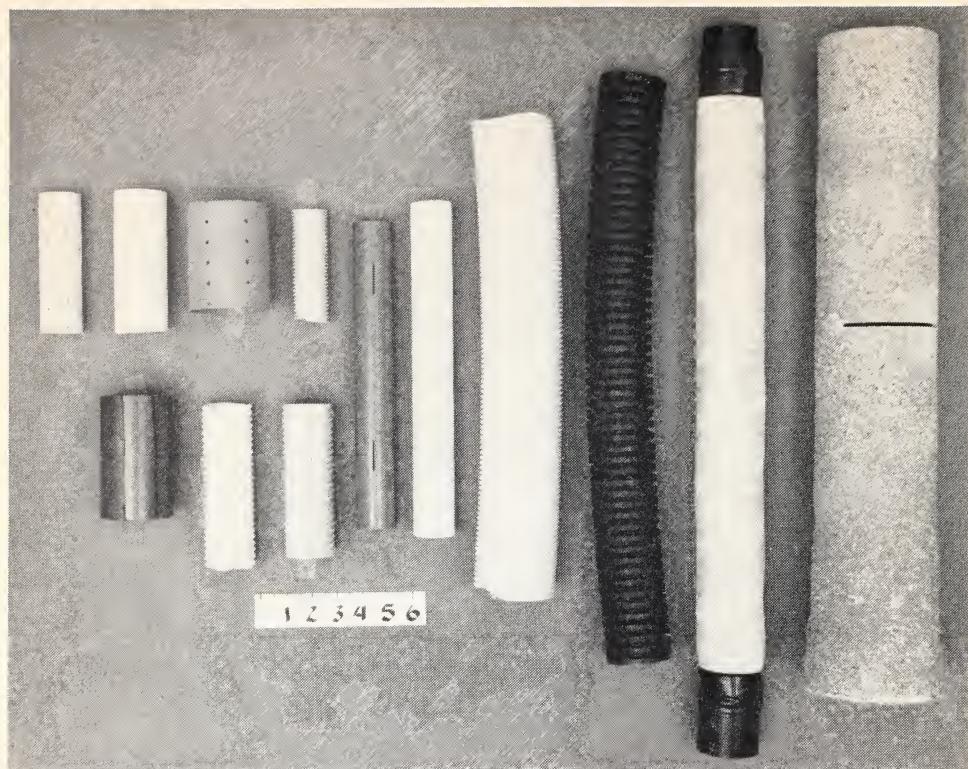
Perforated plastic tiles 1 to 4 inches in diameter are being tried experimentally and used to a limited extent. Indications are that the low price of materials and ease of installation may make these competitive with the standard concrete and clay installations.

iar with the American Society of Testing Materials specifications and are prepared to meet them. Sulfate-resistant cement should be used in the manufacture of concrete tile to be used where sulfate salts are present. Cracked, broken, or otherwise defective tile should never be used. Cracks can be detected by gently striking the tile with a hammer or metal rod. Good tile will have a clear bell-like ring. Under proper conditions of manufacture the choice between clay and concrete is usually based upon cost. Concrete tile is made in sizes from 4 inches up to over 100 inches, while clay tile is usually available in sizes ranging from 4 to about 30 inches. In the smaller sizes tile is made in 12-inch lengths with square-cut ends while the larger sizes are in 24-, 30-, and 36-inch length with fitted

ends similar to sewer pipe and concrete irrigation pipe. Fitted ends are easier to install on line and this type of pipe is increasing in use. The crack spacing at the joints is the point of entrance of water into a tile line and the spacing depends upon irregularities in the ends of the tile. This spacing usually ranges from $1/8$ to $1/16$ of an inch and very little is gained by increasing the crack width. Under nonsubmerged conditions, increasing the crack width will have very little effect upon the movement rate of water through soil enroute to the tile line. Laboratory research has shown that doubling the width of the tile cracks increases the rate of flow into drains by about 10 per cent.

Depth of installation. In areas of general high water table or where salts

RELATION OF WATER LEVELS
TO CROPPING PRACTICE
KINGS COUNTY
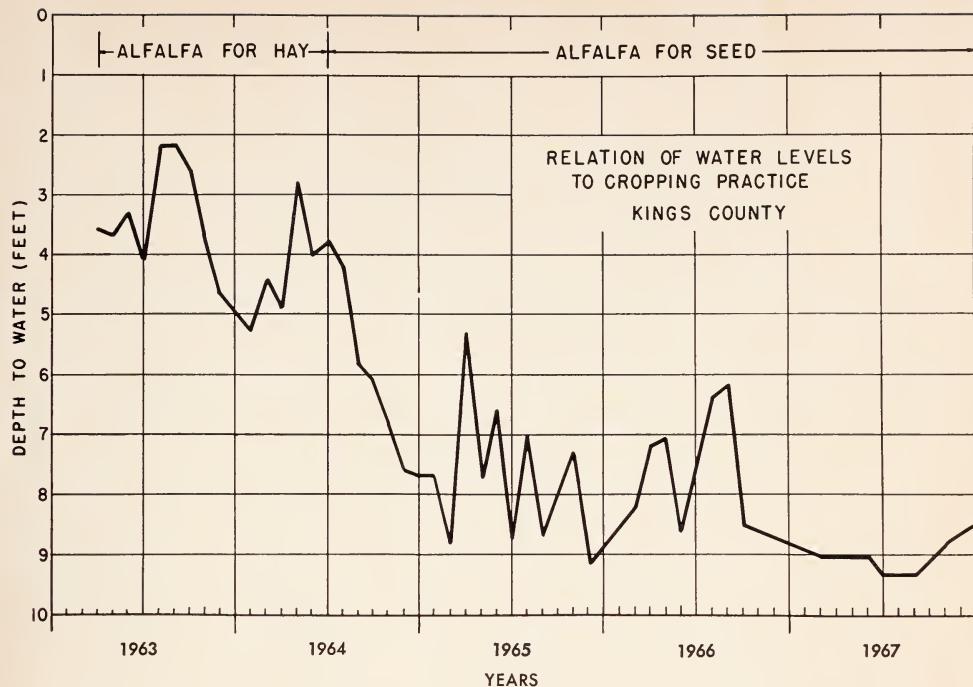
Water table fluctuations indicate that with high-water-using crops (such as alfalfa for hay) a high-water-table condition prevails in the field, while with a low-water-user (such as alfalfa for seed) the irrigation water contributes less to the water table, resulting in a low-water-table condition.

occur in the water and soil, drains should be relatively deep. It is necessary to maintain a water table at such a depth that water rising by capillarity from the water table will not reach the ground surface from which it can evaporate and deposit the dissolved salts. For medium-textured soils, the water table should be a minimum of about 5 feet, and for fine-textured soils about 6 feet. This means that for salt control, drains should be placed greater than 6 feet in depth.

There is opportunity for crop diversification on many of the irrigated farms in California. Different crops have different rooting characteristics, with some rooting to shallow depths and some deeper, and ranging from 1 to 10 feet. Any curtailment of natural rooting will have an adverse effect on production. Since tile drains are relatively permanent the property owner

should install them as deeply as possible to develop the deepest root area for any crop that may be grown. A drain cannot lower the water table below the depth to which the tile is laid. Tile laid above the water table will not intercept downward percolating water, and no water will be collected until the water table has risen to the tile. Except in the immediate vicinity of the tile line the water table will always stand higher than in the tile.

Spacing of tile lines. The spacing between tile lines should be such that the water table midway between the lines is not more than 1 or 1½ feet above the flow line in the tile. This requires tile depths at 7 to 8 feet in many of the irrigated areas. The deeper the tile, the greater the tile spacing can be to obtain the same minimum depth of water table. In stratified soils it is advisable to place tile in the most per-
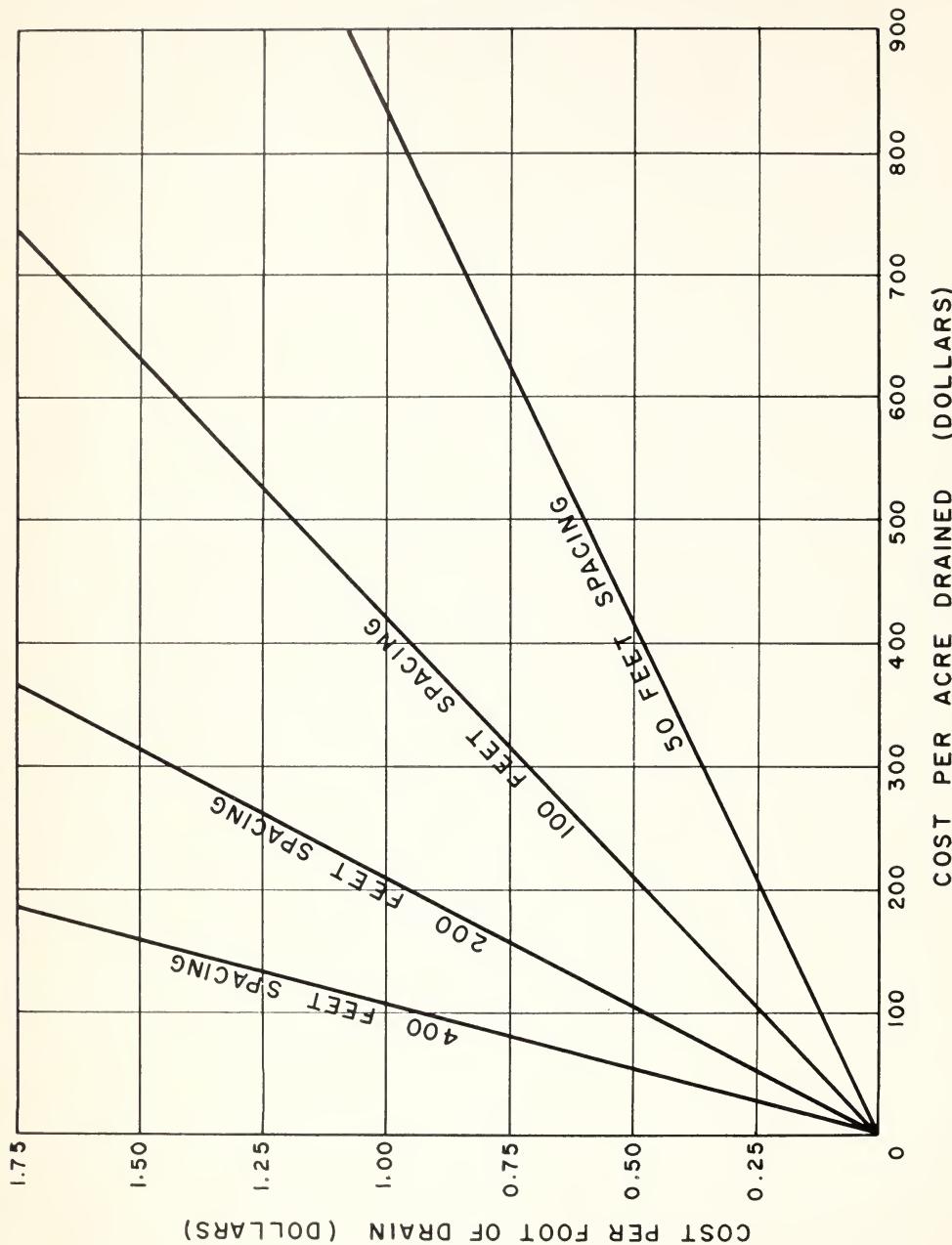
Diagram showing relationship of tile spacing to cost per acre of drained land. Assuming tile costs of $0.75 per foot; if the spacing is 400 feet the cost per acre is about $80.00, but if spaced at 100 feet the cost is about $320.00 per acre. This is one good reason for installing initial tile lines at a wide spacing and returning with additional tile between as the need arises.

meable layer—provided, of course, this is below the depth to which the water table should be lowered, and within a depth that can be economically reached. Where stratifications are undulating or discontinuous it may not be possible to place the tile in the more permeable layer, because the tile must be on grade and continue to a point of discharge. Considering cost and soil conditions, tile should be placed as deeply as possible.

Spacing between tile lines depends upon the texture of the soil and the depth of tile below the ground surface. Since water usually stands nearer the ground surface midway between drains, the depth at this point determines whether or not the drains are lowering the water table satisfactorily. Water usually moves through coarse-textured soils more rapidly than it does through fine-textured ones. Therefore, drains can be spaced greater distances apart in coarse-textured than in fine-textured soils. Soil texture is generally used as a guide to the rate of water conductivity. In most cases it is a satisfactory guide but in others, where such things as the method of soil deposition may alter the conductivity, soil texture may be misleading. Differences may be detected by reliable investigations as previously discussed or known from local experience. Generally, wide spacings are adopted on a trial basis with additional laterals installed midway between if they prove necessary.

In an irrigated area over a general high water table condition, with tile installed at 6- to 8-foot depths, drains may be placed 300 to 600 feet apart in sandy soils and 100 to 300 feet apart in clay soils. In instances where crops requiring frequent irrigations are grown on coarse-textured soils there may be excessive contributions to the water table. These conditions may require tile spacing in coarse-textured soils similar to that in fine-textured soils.

Grading for rapid drainage. The more fall that can be secured, the more rapid will be the drainage, and the smaller will be the tile size necessary to carry a given quantity of water. The natural grade of the land, determined by a survey, should be used when feasible. The grade on which tiles are laid is the only design factor that can be accurately determined. Other items such as depth, spacing, and discharge are based on estimates. Seldom can one grade be maintained throughout a drainage system, or even one line if it is very long. Often the lateral grade differs from that of the main or trunk drain.

Changing grade should be kept at a minimum but may be done where necessary. It is much better to increase grade than to decrease it. It is more important that tile be laid true to the grade accurately determined than it is that any particular grade be used. The grades to strive for in design and installation are between 0.1 foot per 100 feet and 0.5 foot per 100. Tile on flatter grades must be laid more accurately than on steeper grades because minor deviations from true grade may lead to deposition and clogging of the line. With grades greater than 0.5 foot per 100 feet, drain water may move through the soil on the exterior of the drain and cause cavitation, thus allowing the tile to settle out of line with eventual failure. It is reasonable to expect tile to be laid within $\frac{1}{4}$ to $\frac{1}{2}$ inch of true grade, and there should be less than $\frac{1}{4}$-inch variation between adjacent tile. A coarse sand base of 2- or 3-inch thickness makes an excellent bedding material for a true grade and the tongue, and groove joints are a guarantee against variation in line at the joints.

Size of tile. When the maximum amount of water to be drained from

TILE DRAINAGE CHART
ACRES DRAINED BY VARIOUS SIZES OF TILE
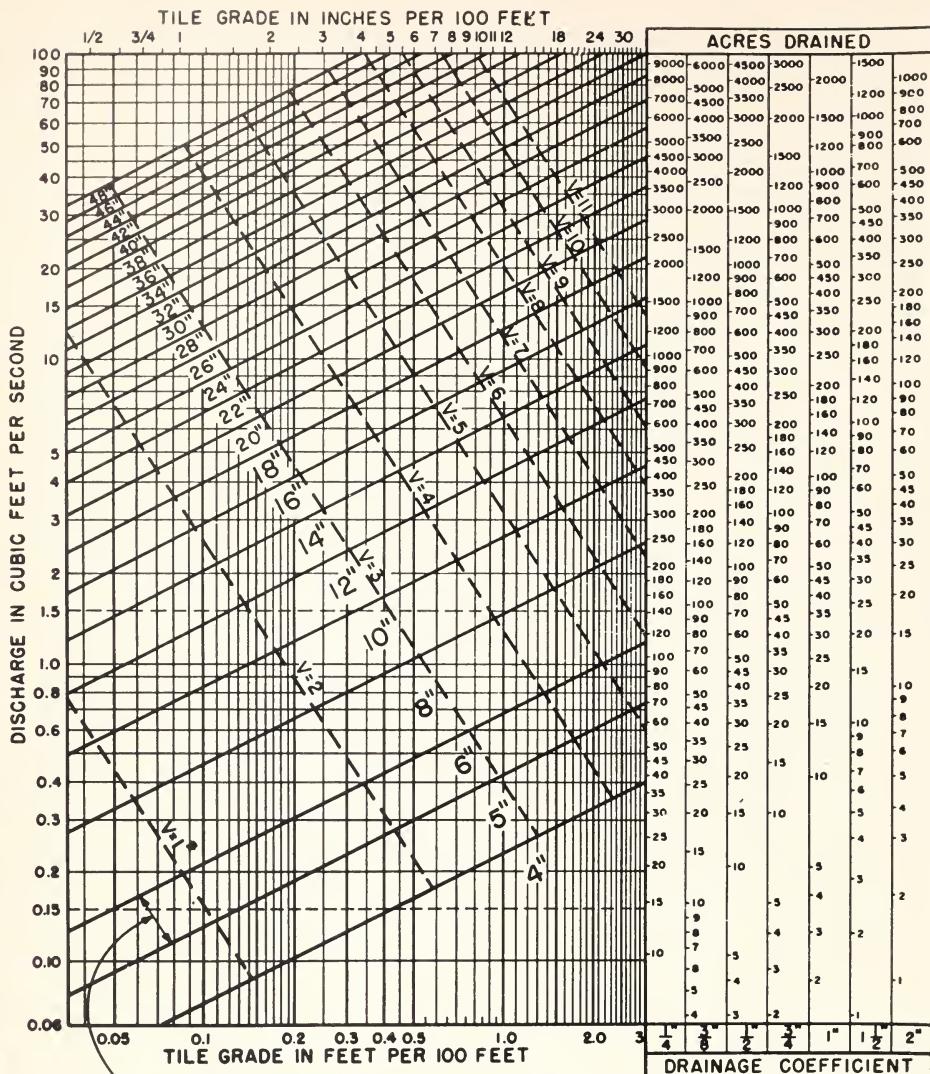
Space between lines is the range of tile
capacity for the size shown between lines.

■ V = velocity in feet per second

Reference : Yarnell-Woodward Formula $v = 138 r^{\frac{2}{3}} s^{\frac{1}{2}}$

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As an example of the procedure for use of this diagram, assume that it is necessary to remove ¼ inch in depth of water from 80 acres in 24 hours and a grade of 0.2 feet per 100 feet is available. Follow the right hand column marked ¼ inch above drainage coefficient, up to 80 which represents the area; then follow a horizontal line to the left of 80 until it intersects a vertical line up from 0.2 along the ordinate designated tile grade in feet per 100 feet. This intersection occurs in the space designated as 10 inch, thus a 10 inch tile should be used. The diagram also shows that in the case of the assumed example the flow in the 10 inch tile will have a velocity of slightly less than 2 feet per second and the discharge would be about 0.85 cubic feet per second. Similarly, if the amount of water in cubic feet per second is known the size of tile required can be determined by starting on the left hand margin and moving along a horizontal line representing the discharge until the line intersects a vertical line from the correct grade.

Linerods with crossbars along which the trenching machine operator sights to keep on grade. Tile and envelope materials are distributed along the line before the digging begins.

a tract is known or has been computed, and the grade for the drain has been determined by surveys, the size of the tile to use can be computed. Tile is usually manufactured in sizes starting with 4 inches and increasing in 2-inch increments, such as 4, 6, 8, et cetera, up to 24 inches. Some factories make 5-and 7-inch tile. Where computations indicate a size not manufactured, the next larger size available should be used. Tiles 4 and 6 inches in diameter are the most commonly used and the cheapest. Current practice indicates that seldom should 4-inch lines extend over one quarter of a mile or about 1,300 feet. If laterals are much longer than this the tile size should be increased to 5 or 6 inches at the lower end. With increasing length of drain the size should be increased about every quarter mile.

Wherever possible, a tile drainage system should be designed to keep laterals relatively short. Six- and eight-inch tiles are usually large enough for mainlines into which laterals discharge. Tile larger than 20 inches is expensive, but with the improvements in monolithic concrete pipe this type of structure for mainlines is being used more frequently.

The capacity of different-sized tile varies as the square of the diameter. A 6-inch tile will carry more than twice the flow of a 4-inch line on the same grade. The ratio is as the square of 4, which is 16, to the square of 6, which is 36. Increasing the grade increases the velocity and the carrying capacity.

Surveying for tile installation. Before any trench can be excavated or tile laid, the lines along which the drains are to be installed should be staked out and clearly marked. This is done by setting a marker stake at each 50 or 100 feet upon which is written the distance from the outlet. For lateral drains, the zero or starting point should be its connection with the main. The first stake, at the outlet, is

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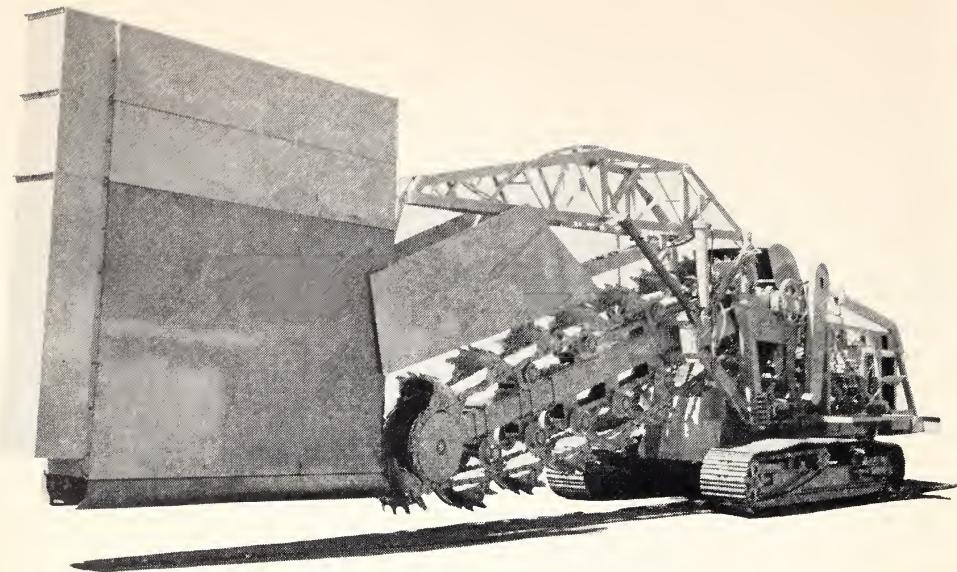
Modern ladder-type tile-laying machine. Large metal shield protects the man laying tile against cave-ins.

marked 0 + 00; the next one at 100-feet distance is marked 1 + 00; at 200 feet is marked 2 + 00; et cetera. If stakes are required at intermediate points, for example 335 feet from the outlet, they would be marked 3 + 35. Next to each of these marker stakes a "hub" or grade stake is driven into the ground so that the top is flush with the ground surface. It is from the top of the grade stake that all measurements of depth or "cut" are made. This stake must not be disturbed until the job is completed. The nearer edge of the trench should be laid off parallel to and about 12 inches from the line of stakes.

Elevations of the hub stakes are found by the use of an engineer's level. This information is plotted on profile paper; the grade line of the tile is established; and the depth of cut at each station is computed. The grade line is the bottom of the trench and is the line on which the tile is actually laid. The depth of cut should be written on the upstream side of the marker, and recorded elsewhere. It is better to do both as some of the grade stakes may be disturbed or the records lost.

For machine-dug trenches, targets are set up ahead of the excavator so that the crossbars are parallel to and a given number of feet above the established grade line. The operator, with a sight bar on his machine, sights along the crossbars and keeps the machine constantly on grade. A skilled operator has no trouble in keeping within a fraction of an inch of true grade.

For hand-dug trenches a similar method is used except that a cord is stretched taut over the crossbars. Frequent measurements are taken down from the cord to ascertain whether or not the trench is at the proper depth.

Recent experiments with light beams for control of excavation depth suggest a potential for this type of equipment.

It is essential that tile be laid accurately to the established grade because variations of only a fraction of an inch are allowable. This is especially true where small tile (4 to 6 inch) is laid on flat grades of 0.1 or 0.2 per cent.

Modern tile laying. Trenching machine in left center with man on bank handing tile into shield to installer. Skip loader in right center dumping envelope material into hopper on machine. Bulldozer on left is back-filling trench.

Excavating. After the line is completely staked and the grades and "cuts" established, excavation may begin. Short drains may be dug by hand, but when the job is extensive it is usually cheaper to hire a contractor equipped for this type of work. Trenching machines, backhoes, and draglines—the machines used in drainage excavation—are too expensive for the farmer to own and contractors are available in most communities.

Whether hand- or machine-dug, the excavation should always begin at the outlet so that the trench can be kept reasonably free from accumulated water. Where a sump with pump is necessary to raise the water into a main drain, the sump should be complete and ready for use before the tile line is started. If possible the work should be done during the driest part of the year which, in California, is usually September and October. Even though construction is done during the driest part of the year, in most instances water will be encountered and one should be prepared to work in a wet

trench. Although the fall season is the best time for drains to be installed it is not possible for the installation contractors to operate economically during only two months of the year.

Shoring vertical walls. Safety Orders of the California Department of Industrial Relations require that vertical wall trenches must be shored and braced when more than 5 feet deep. This of course is necessary to the safety of workmen. The Safety Orders also state that sloping of trench walls may be substituted for shoring and bracing if the slope is sufficient to eliminate the hazard of moving ground. Sloping is not considered adequate unless the trench depth is less than half the combined width of the trench top and trench bottom. Ordinarily, a slope of $\frac{3}{4}$ to 1 is required to obtain this minimum combined width.

A method of overcoming the shoring problem of trenches has been the use of a steel or aluminum shoe attached directly behind the excavation buckets of the trenching machine. This box-like container has width and depth dimensions similar to the trench and is sufficiently long to allow a man to sit and lay tile as it comes from the surface by a chute or elevator.

Another method of obtaining the desired depth is to use a scraper to excavate a foot or two of soil along the tile line the width of the scraper. The trenching machine can then be used on the excavated area and kept within the 5-foot limitation.

Laying the tile. Adjacent tiles should be placed as closely together as they will lie. Although water enters a tile line only at the joints, there is no need to purposely separate the tile. Roughness in manufacture will allow enough space for water to enter. Water does not enter the line through the walls of the tile. Many of the deep tile-laying machines are equipped with a hydraulic or pneumatic ram which

Two-inch plastic tile being installed from large drum attached to trenching machine. The belt is conveying excavated soil to rear of machine and dumping it into trench on top of envelope-surrounded tile.

forces the tile together at a pressure of several hundred pounds per square inch. Where soil conditions are favorable, tile can be held in place against the preceding tile by the tile layer's foot until the next joint is ready to be placed. Both of these methods are necessary to prevent the tile from being pulled away from the preceding joint by the forward movement of the trenching machine.

There may be places where soil conditions are so bad that it is impossible to lay tile in a narrow trench such as that dug by machine. When this soil condition exists it is necessary to dig a wide trench or ditch having very flat side slopes, and on occasions to place the tile on a wooden cradle or on a thick bed of gravel.

Need for a cradle. Tiles laid in material that is extremely unstable, such as peat or quicksand where the weight of the tile will cause them to sink or to get out of alignment, may require a cradle to hold them in place.

A cradle consists of two boards, usually 1 × 3 inches, laid parallel and about 3 inches apart. These are laid flat, and are held together with cross

Cradles are used for supporting tile in unstable material.

pieces nailed to the underside at about 5-foot intervals. Cradles can be made in sections up to 16 feet in length and the individual sections should be fastened together to avoid loose joints. The tile rests between the two parallel boards. Sometimes it is necessary to nail the cradle to posts driven into the bottom of the trench. Cradles are very useful in draining peat soils if the underlying material is uneven and the tile rests part on solid material and part on unstable peat. Tile requiring cradles should be covered with envel-

ope material. Cradles add materially to the cost of drainage. Coarse sand or fine gravel make an excellent bedding material for tile from the standpoint of leveling to grade and providing a firm base.

Need for envelope material. In some areas containing silt or very fine sand, coarse sand or fine gravel is sometimes placed in the bottom of the trench before the tile is laid. After the tile is laid it is surrounded with a layer of envelope material about 2 or 3 inches thick.

The modern tile-laying machine is equipped to place the envelope material automatically both under and around the tile. The amount of material used will depend on the difficulties encountered in laying tile, but an envelope 2 to 3 inches thick is usually sufficient. Experience has shown that it takes about 2 cubic yards per 100 feet for 4-inch tile, about 2½ yards per 100 feet for 6-inch tile, and 3 yards per 100 feet for 8-inch tile.

Where course sand or fine gravel is unreasonably expensive straw has been used successfully. Glass fiber which comes in rolls and is applied directly over the top and sides of the tile as it is installed is sometimes used.

During the 125 years that tile drains have been used sucessfully in the middle west and eastern United States, practically no envelopes have been included in the installations. There are many hypotheses, both for and against this, but very little factual proof. Experience indicates that where the tiles are to be placed in a fluid material containing very fine-grained particles which can pass into the line through the joints, it may be advisable to use an envelope. Where tile drains have been installed on the proper grade, the right size, and on the correct alignment, and have not been moved out of alignment with use, the plugging of the interior of the drain

with soil is practically unheard of. The use of a gravel pack to increase the size of the drain may not have the desired effect because increasing the diameter has very little effect on the movement of water into the line. In the laboratory, with tile running full with no back pressure and placed at 9-feet depth, increasing the diameter 300 per cent from 4 inches to 12 inches, increases the flow into the tile line only 23 per cent. Field observation tends to indicate that there may be increases in flow rates from drains with envelopes as compared with those without. Also some evidence is being uncovered of increased flow rates with thicker envelopes as compared with thinner envelopes. Envelope material usually costs less than 10 per cent of the total installation cost; therefore, its use is recommended rather than take a chance. When the costs become greater than 10 per cent, a careful determination as to the need of envelope material should be made.

Nearly all farmers have tractors to which can be attached bulldozers, and except in places where it is difficult to get a tractor the backfilling is done with this equipment. Most large commercial machines are equipped so that backfilling is carried on with the excavating. At one time, tar paper was unrolled on top of the tile as it was installed but this is seldom used now. If no envelope material is used around the tile, it is advisable to cover it by hand with a layer of soil which will keep the tile from being pushed to one side by the backfill dropping on it. This process is called "blinding" and it should be done with a shovel, using soil taken from the side of the trench near the top. This covering should fill the trench on both sides and above the tile to a depth of 3 or 4 inches. When the tile is laid in a machine the blinding is done by knives protruding from the sides of the shoe. As the machine

moves the knives slice off a small section of soil on each side of the trench. The soil is deposited on the sides and top of the tile. The remainder of the backfill can be pushed into the trench with a bulldozer or other convenient means with little danger of disturbing the tile. All of the excavated material should be returned to the trench even though it temporarily forms a mound. As the material settles, practically all soil will go back into place. On contract jobs the backfilling is usually included in the contract, but the final settling of the trench may be left to the farmer. The farmer usually plows a furrow down the middle of the filled trench and water is allowed to run in the furrow. Settling a trench with water should be done with great care as there is a danger of the water carrying so much soil into the tile that it may become clogged or misplaced.

Manholes or siltboxes. These may be placed at intervals along a tile drain to catch and retain silt entering the line if there is reason to think that difficulty with silt will occur. Silt boxes offer a convenient point for inspection and maintenance. At important junction points where two or more lines meet, a silt box is a convenient means of making these connections. It also serves as an observation point to determine whether a line is producing the water to be expected or whether it may be clogged. If a silt box is placed in a cultivated field, however, it interferes with cultivation and unless properly maintained may even be a menace. There are, however, occasions where a silt box is useful and even essential to the proper functioning and maintenance of a system. The bottom of a silt box should be at least 1 foot below the flow line of the outlet tile and the incoming tile should enter at a higher elevation than the outlet tile.

Manholes and silt boxes are most easily made of large-size concrete pipe placed one on top of the other. The floor of the box should be concrete and the cover should be securely fastened and locked. The most common method of joining two lines is to cut a hole in the larger tile with a chisel and fit the end of the smaller tile into it, chipping off the edge to make the inside smooth and cementing the joint.

Cost of tile. Costs will vary with amount and size of tile, depth of installation, type of soil, proximity of location of installation to the source of tile, envelope material, and the drain-tile contractors themselves. The top of the next page shows a composite of data obtained from records of 18 county offices of the United States Department of Agriculture — ACP throughout the state. They may be considered as a rough guide for 5- or 6-foot depth of tile and include cost of trench, tile, envelope, and backfilling.

Maintaining the Tile Drain

Although all types of drainage systems require maintenance, none requires so little as a properly installed tile system. Very few commercial crops will send their roots into tile lines to clog them. In the field, most plants will not grow with their roots in standing water for any extended length of time. There are certain trees, however, such as willows, cottonwood, tamarix, and sometimes eucalyptus which will cause trouble if they are within 50 or 75 feet of a drain. All trees of this nature within 75 to 100 feet of a tile line should be removed and their roots killed. When tile lines become filled with tree roots, usually the best way to clear them is to dig up the entire clogged section and replace it. At the same time the troublesome trees should be removed.

Tile lines draining springs or seep areas may become stopped with roots,

[35]

	SIZE OF TILE (INCHES)				
AREA	4	6	8	10	12
North coast	$0.65	$1.00	$1.25	$1.65	$1.80
Central coast	0.70	1.10	1.30	1.70	1.80
South coast	0.45	0.60	0.70	1.05	1.30
Sacramento Valley	0.90	1.25	1.50	1.80	2.00
San Joaquin Valley	0.60	0.80	1.05	1.25	1.50
Sierra foothills	0.60	0.75	0.95	1.25	1.50
Desert	0.45	0.55	0.65	1.00	1.50

especially if at some point along the line they pass through areas where the soil is not saturated. In such instances roots may enter in search of moisture. One way to prevent this is to cement the joints of the tile running through the unsaturated area to make a solid pipeline. Since water will not move into a drain from unsaturated soils there is no need for a drain in such an area.

Sugar beets have been known to stop up tile lines lying as deep as 5 feet. When a line is clogged with roots of an annual crop, such as beets, it will probably clear itself after the crop is removed and the roots die. Roots stop fine sand and silt which would normally pass on through a tile line.

Silt or very fine sand sometimes gets into tile lines and clogs them, but usually this occurs within a few months after installation; lines that remain open for a year or more may be safe from such obstructions. If the line is not completely clogged, and there is some passageway through the tile, it can sometimes be flushed out with a hose working from the lower end. This may necessitate uncovering the line at some point downstream from the obstruction, and obtaining sufficient pressure to force a stream of water against the obstruction.

Saturated very fine sand may, under certain conditions, be so buoyant that it will enter the tile line along with drainage water and eventually leave a hole or void under the tile. When this hole becomes large enough the tile may fall into it, thus breaking the line and destroying the drainage. This may also occur if care is not exercised when settling the backfill with water. The only remedy for such a break is to take up that portion of the line and replace it, using sufficient gravel or envelope material around the tile so that it cannot recur.

Where there is likelihood of fine material entering a line through the envelope, the upper ends of the tile lines may be constructed to slope upward and approach the ground surface in the bottom of an irrigation ditch. Alfalfa valves may be placed on the end of the tile, and when flushing is desired the valves are opened and irrigation ditch water allowed to enter the line.

In some isolated instances organic growth or mineral deposition may take place in the tile lines and at the joints. Using a rod and brush and, in some instances, introducing acid into the line helps to relieve the growth condition. If there is a need for periodic use of a rod or brush in lines, a sloping riser pipe installed every 400 or 500 feet along the line would save excavating and breaking into the line for brushing.

If manholes or silt boxes are placed on tile lines, they should be inspected monthly for at least a year and then once or twice a year and any deposits cleaned out when necessary.

OTHER COVERED DRAINS

French drain. This is a trench or ditch backfilled with rock, brush, or-

ganic material or anything which provides more rapid conductivity of water than the natural soil. It is better to spend a little more money and install tile once the trench has been excavated. French drains will eventually plug up and their limited capacity for carrying water precludes recommending them.

Mole drain. This type of drain was used for drainage before the use of tile, and at best is only a temporary method. A mole is constructed by drawing through the soil a subsoil attachment behind which is a torpedo-shaped piece of metal 2 or 3 inches in diameter and about a foot long. This leaves a cylindrical opening in the soil to receive and convey water to drainage ditches. As with other drainage construction, the mole begins at the outlet ditch and must be constructed under level land in order that low spots in the mole hole are not formed to store water. The principal advantage of mole drainage is its low first cost. At a depth of 30 inches and 20 feet spacing between lines it is estimated that the cost is less than one tenth of that for tile drainage. The chief disadvantage is its short life of from one to three years in most soils and the shallow depth to which it is installed.

A recent development with *plastics* is to attach a large drum of 2-inch perforated plastic tubing to the machine drawing the subsoiler and mole. As the machine moves forward the tubing is unwound and placed in the hole created by the mole. Another system attaches a role of perforated sheet plastic to the subsoiler, and as the mole is opened the plastic is formed into a continuous cylinder which lines the mole hole. The purpose of the plastic tubing is to protect the mole hole from collapse or clogging from soil. Moles both unlined and lined with plastics are too shallow for use in most irrigated areas where high water tables are a problem throughout the growing season. However, they may be effective in hastening drying of the soil for earlier planting in areas where the water level is too high at planting time but drops to a satisfactory depth during the growing season.

Pumped and reverse wells. Both pumped and reverse wells are used for drainage where a good aquifer is present. About 500 pumped wells are working successfully on the east side of the lower San Joaquin Valley. Here a high water table condition is controlled by installing wells at about ½-mile intervals and pumping the water into irrigation ditches for use. Directly across the Valley on the west side a few dozen have been installed and are unsuccessful. This failure is due to the difference in the valley fill material. On the east side of the valley decomposed granite rock from the Sierra has been washed into the valley to form about 200 feet of aquifer, while on the west side clay from the Coast Range has formed valley fill material.

The reverse well is a well in which surface, or in some instances perched water, is allowed to drop into an open well to a deep water table to mingle with the deep water. This usually works for a short time, until algae and corrosion form in the well to seal the openings so that the introduced water cannot get out of the well. **As there are laws pertaining to mixing surface water with groundwater, county public health offices should be contacted before this type of well is constructed.**

If the source of excess water is upward leakage from an artesian aquifer, wells penetrating the aquifer can be pumped. For some distance around the well artesian pressure is reduced and upward leakage is retarded. The feasibility of a drainage well depends primarily on the area of influence. If the area affected is small, many wells are

Two examples of pumped wells for drainage. The picture at left shows a well on the east side of San Joaquin Valley pumping about 2000 gallons per minute from about 200 feet of excellent sand and gravel aquifer. The other picture shows a well about five miles away on the west side of San Joaquin Valley pumping about 50 gallons per minute from a poor aquifer which is common in the area. Both wells are discharging into an irrigation ditch.

required and the cost is excessive. Usually test wells are drilled, pumps installed and operated, and the area of influence determined by measuring water levels in adjacent observation wells or piezometers. Well spacing, rate of pumping, and other construction and operational features are determined from these tests.

Even under favorable conditions pumped drainage wells seldom are economical unless the drainage water can be used for irrigation or other purposes. The value of the drainage water for irrigation nearly always offsets the pumping costs. A major factor in suitability of drainage water for irrigation is quality. Even when quality is poor, if mixed with a better quality irrigation water, the dilution may be sufficiently great to alleviate danger.

In some locations, drainage of artesian water can be accomplished by drilling wells through the bottom of a ditch into the confined aquifer below. Water flows out of wells by artesian pressure into the ditch which conducts it away. The water table in the area cannot rise above the water level in the ditch, and drainage is accomplished without pumping.

In areas too wet to support mechanical equipment, dynamite can be used to construct shallow ditches. This measure may allow the wet areas to drain sufficiently for equipment to be used to construct the deeper drain usually needed. Dynamite is extremely dangerous and should not be considered except by an experienced user.

IRRIGATION RETURN WATER
SYSTEMS

A system of surface drainage of irrigation water, which has become very popular in many irrigated areas in California, is the return water system. This system generally consists of a basin, or sump, about $\frac{1}{4}$ to $\frac{1}{3}$ acre in size at the low point of the field, a small pump and motor unit, and pipe for returning the waste water to the
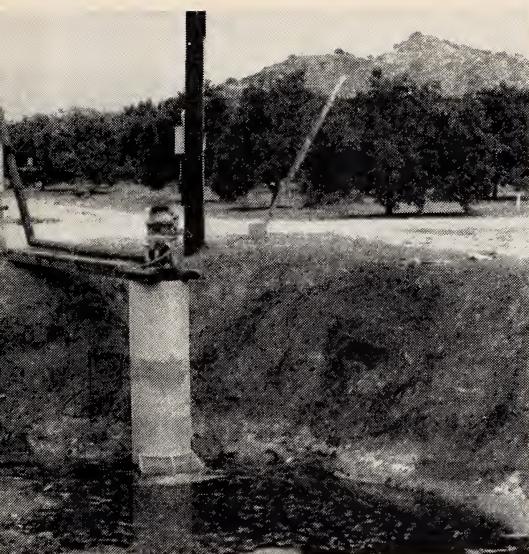
Typical open sump return flow reservoir and pump.

Typical concrete pipe return flow reservoir and pump.

main irrigation system. A sump can be constructed commercially with a bull-dozer or scraper in less than a day's time. Dirt from the sump hole can be pushed into a levee around the sump or if needed can be used for filling low spots in the field. On valuable fruit or other crop land, an open sump may be a waste of land. If so, 6- or 8-foot-diameter concrete pipe joined and mortared in an upright position is usually satisfactory. In such an installation the water should be screened of debris and the silt allowed to settle out.

A return water system not only serves to remove waste water which may become a nuisance or even damage the crop, but the water reclaimed is usually less expensive than it was originally. Studies show that the cost of the return water, including depreciation and operation, ranges from $1.00 to $5.00 per acre-foot.

LEACHING TO RECLAIM SALINE SOILS

When salinity in soils becomes too high for efficient crop production, it must be removed or the land must be

abandoned. The common method for removal is by leaching of salts with water: salts dissolve in the water passing through the soil and out of the area. Leaching may be a natural process with rainfall or may result from irrigation practices, but usually water is applied specifically for leaching. In all cases, water must pass beyond the root zone to remove excess salt from the root zone. Therefore, leaching is impossible without natural or artificial drainage.

The common method for removal is to surround the salinized area with levees (similar to rice levees 2 to 3 feet in height) and to cover it with water. The area flooded may be as large as possible but still small enough so that all soil except the levees is underwater. Wind and wave action also may affect the size of leaching ponds. It has been found that as a general rule 1 foot of water for each foot-depth of soil will reduce salinity of the surface foot of soil about 80 per cent; 2 feet of water will reduce salinity in the surface foot about 90 per cent, in the second foot about 80 per cent, et cetera.

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Fields being leached.

Irrigation water displaces soil solution in an irregular manner. Applied water passes rapidly through the large pores and flushes out salt; the small pores conduct water less rapidly and take much longer to flush clean. As long as water is ponded on the surface, it continues to move through the large pores, using up water and inefficiently leaching the soil profile. Intermittent ponding or sprinkling sometimes provides a more thorough removal of salts from the soil profile, and may be the most efficient method of leaching where water costs are high.

Under certain conditions, highly saline water can be used for reclamation of alkali soils with considerable savings in the amount of chemical amendment required. This is possible only when analysis of both the highly saline water and the alkali soil shows that the water is of much better quality than the soil. After an initial treatment with the undiluted saline water, the alkali content of the soil will be reduced. The saline water can then be diluted with low salt water and the soil leached again. The final step may require the application of a chemical amendment followed by leaching with good-quality irrigation water.

MIDDLE ELEVATION AND LOW ELEVATION
DESERT SECTIONS OF CALIFORNIA

FROM

CALIFORNIA'S PLANTCLIMATES
AGRICULTURAL EXTENSION SERVICE
UNIVERSITY OF CALIFORNIA
1964
(IN PRESS)

PREPARED BY

MARSTON H. KIMBALL, EXTENSION BIOCLIMATOLOGIST

N

HIGH ELEVATION

WHITE MOUNTAINS

INYO MOUNTAINS

OWENS DESERT

SIERRA NEVADA

PANAMINT RANGE

ARGUS RANGE

DEATH VALLEY

KIAVAH MOUNTAINS

TEHACHAPI MOUNTAINS

SAN GABRIEL

INYO COUNTY
KERN COUNTY
SAN BERNARDINO COUNTY
LOS ANGELES COUNTY
MONO COUNTY

BENTON
BISHOP
BIG PINE
INDEPENDENCE
LONE PINE
OLANCHA
HAIWEE
CHINA LAKE
TRONA
KERNVILLE
ISABELLA
INYOKERN
RIDGECREST
FREEMAN
RANDSBURG
CANTIL
MOJAVE
BORON
BACKUS RANCH
ROSAMOND
ANTELOPE VALLEY
GORMAN
LEBEC
SANDBERG
FAIRMONT
LANCASTER
PALMDALE
ADELANTO
HELENDALE
HINKLEY
BARSTOW
DAGGETT
YERMO
NEWBERRY
LUDLOW
BAGDAD
AMBOY
ESSEX
NEEDLES
BAKER
YUCCA GROVE
SHOSHONE
DEATH VALLEY JCT.
FURNACE CREEK INN
STOVEPIPE WELLS

To Beatty
To Las Vegas
To Searchlight
To Kingman
To Bakersfield
To Los Angeles
To Panamint

SUBZONES: 1.1, 1.2, etc.; 2.1, 2.2, etc. = COOLING TREND

—————— HIGH ELEVATION DESERT BOUNDARY

— — —o— — LOW ELEVATION DESERT BOUNDARY AND TOP OF SUBTROPICAL THERMAL ZONE

—————— SUBZONE BOUNDARY

—···—···— TOP OF DECIDUOUS FRUIT THERMAL ZONE

—————— BOTTOM OF DECIDUOUS FRUIT THERMAL ZONE

——||—— TOP OF RICE-BERMUDAGRASS THERMAL ZONE

——||—— TOP OF RICE-BERMUDAGRASS AND BOTTOM OF DECIDUOUS FRUIT THERMAL ZONES

—··—··— INTERNATIONAL BOUNDARY

— — — — STATE BOUNDARY

— — — — COUNTY BOUNDARY

⊏══⊐ HIGHWAY

⊙ COUNTY SEAT

• TOWN

△ MOUNTAIN PEAK

≈≈≈ HYDROGRAPHY

⤙⤙⤙ AREA OF SIGNIFICANT WINDS Half-arrows indicate approximate lateral boundaries

MILES
0   8   16   24
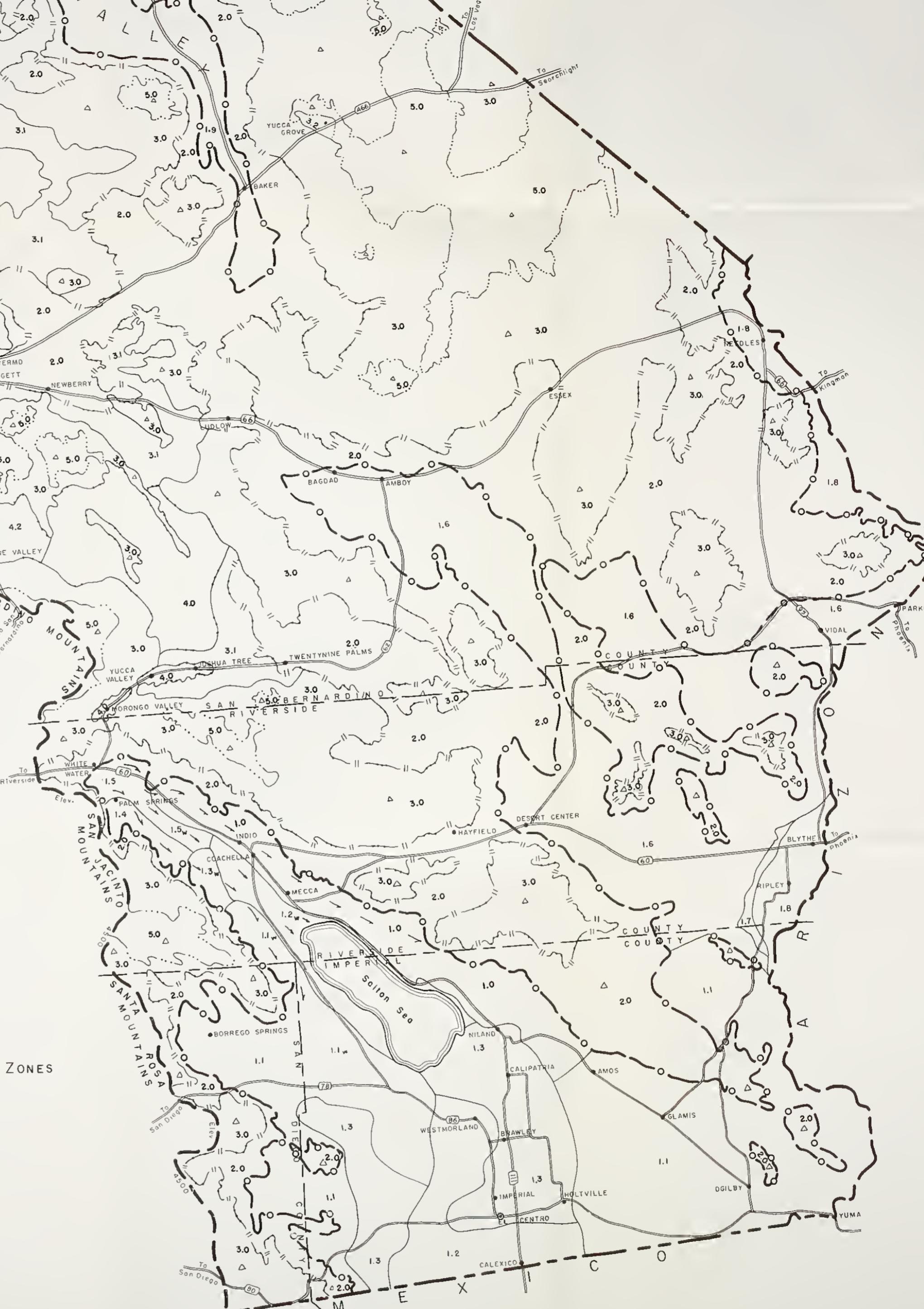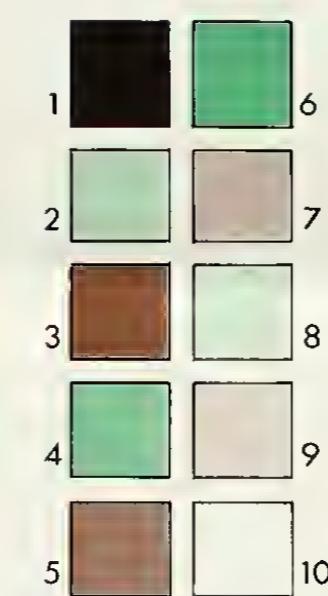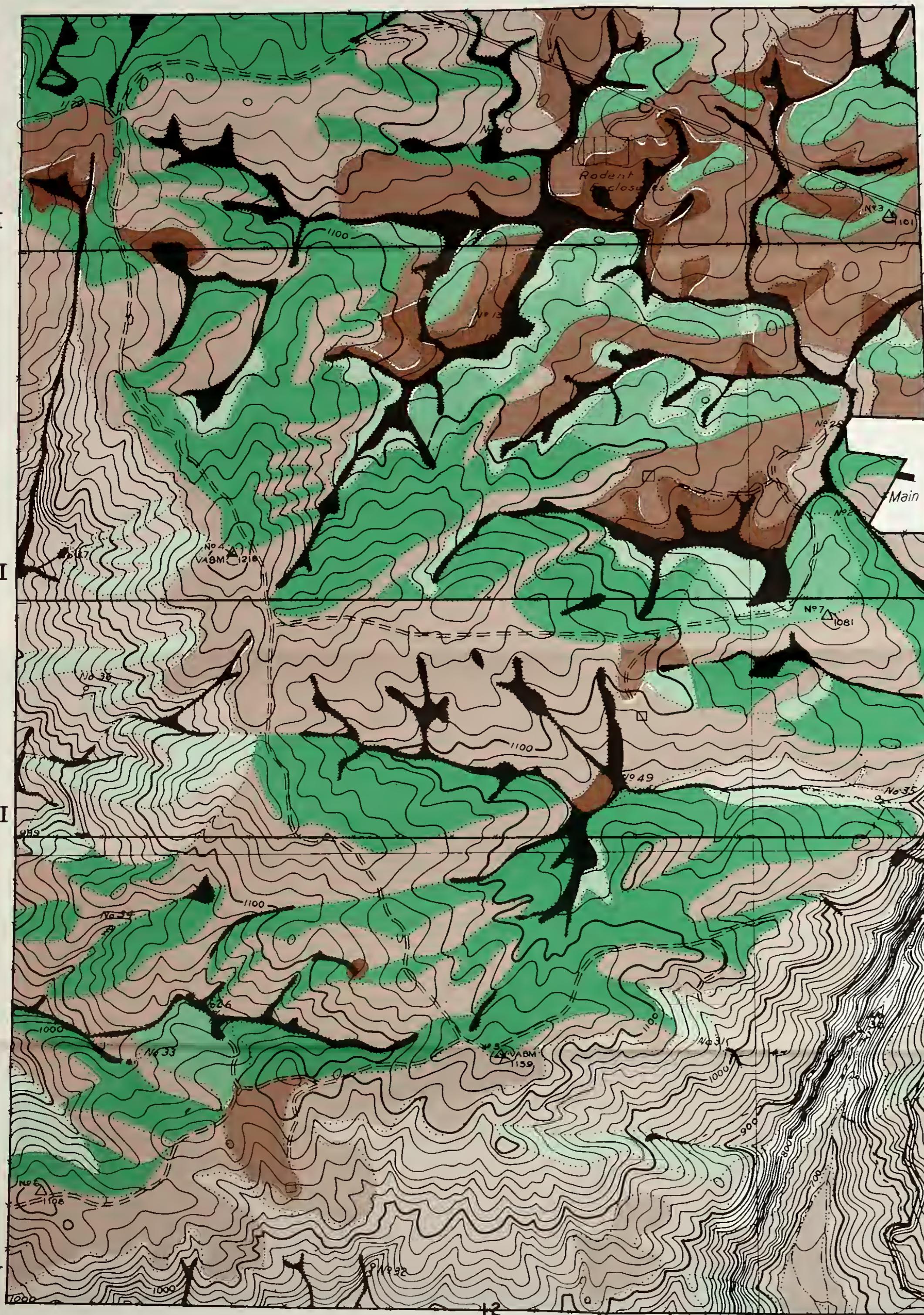
Fig. 1A. Experimental pastures I to VI, showing the extent of the different land classes. Top is north, contour interval is 12½ feet, and the division fence between pastures II and III is one mile long.

Fig. 1B. Experimental pasture XIV, showing the extent of the different land classes. Tap is north, contaur interval is 12½ feet.

XIV